63_ 4_ 2
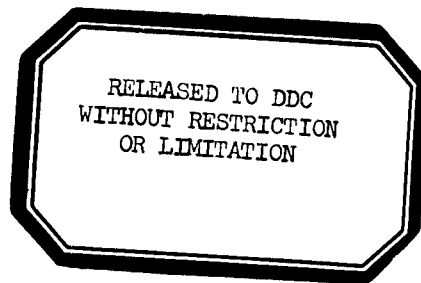
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Final Report   F-B1805

PRECISION RF SENSITIVITY STUDIES
(Evaluations of MARK 1 MOD 0 Squib and
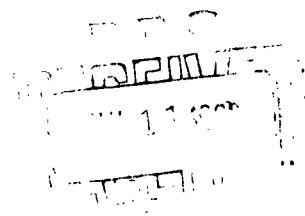MARK 2 MOD 0 Ignition Element)

by

Paul F. Mohrbach
Robert F. Wood
Norman P. Faunce

January 23, 1961 to August 15, 1962

Prepared for

U.S. NAVAL WEAPONS LABORATORY
Dahlgren, Virginia
Code WHR

Contract No. N178-8730

THE FRANKLIN INSTITUTE
LABORATORIES FOR RESEARCH AND DEVELOPMENT
PHILADELPHIA   PENNSYLVANIA

THE FRANKLIN INSTITUTE · *Laboratories for Research and Development*

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ABSTRACT

Developments leading to the establishment of precision RF firing evaluation techniques are set forth in this final summary report. The RF sensitivity of the MARK 1 MOD 0 squib and MARK 2 MOD 0 ignition element has been determined by these newly developed precision firing techniques. Data from 5 to 1000 Mc CW are obtained, differing little from the dc power sensitivity determined from 10-second constant current pulse data.

Many developments preceded the actual tests. Studies of system losses indicated that special matching devices would be desirable, for limiting to reasonable values the power lost in the RF plumbing. As a consequence, a novel shorted stub was developed for use at the higher frequencies. Low-loss lumped-parameter tuning networks were fabricated for the lower frequencies. Toward this same end, the design and construction of the fixture for mounting the initiator under test was given special attention.

Results with precision never before duplicated were obtained by use of a special calibration procedure that was developed. A photo-conductive cell is focused onto the exposed bridgewire of the device to be tested and its response is calibrated against a steady-state dc power input. Following this, RF is fed to the same device and the ratio of the RF to dc level for the same bridgewire illumination is taken as the system calibration factor. In so doing, all losses between the point at which we measure input RF power and the bridge element are lumped. Because of this it is important first to evaluate the losses in the plug or base of the initiator, and, then with this to correct the system calibration factor. For the two items evaluated no detectable base loss was evident up to 1000 Mc.

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1. INTRODUCTION

The purpose of this program was to determine the RF sensitivity over a wide range of frequencies of the MARK 1 Squib and the MARK 2 MOD 0 Ignition Element with an error of less than 5%. The plan required the development and careful calibration of suitable systems of instrumentation. The test procedure was to use the Bruceton routine wherein power is the variable and each initiator is tested at one of several predetermined power levels; the particular level for each being one step higher or lower depending upon whether the preceding result was a non-fire or fire respectively. By following this procedure, testing randomly sampled groups of 40-100 initiators at each of several frequencies we can derive a curve of RF power versus frequency.

In the early days of the program, exhaustive tests were performed to evaluate losses in various matching devices, over a frequency range of 250 to 500 megacycles: Experimental tests were supplemented with theoretical studies of impedance matching, which led to the conclusion that large system losses are inevitable when matching into loads having a small resistive component or large reactive components. Acknowledging that system losses of 50 per cent or more were unavoidable, we proceeded to assemble and test practical systems for firing the two items being studied.

Calibrated RF thermocouples were used in the first attempts to evaluate system losses. These thermocouples were useful for comparing the relative losses of different matching systems. It was soon realized, however, that a better way to determine absolute system loss would involve determination of the RF power actually reaching the bridgewire of the ignition element or squib under test. This was done by means of photo-conductive cells mounted above the bridgewire of an inert device.

The system loss evaluation technique above has one inherent source of error, in that the losses in the base of the ignition element are included in the loss factor obtained. Base losses, if present, should not be included in the loss factor.

Several experiments were made to determine the loss in the base of the MARK 2 MOD 0 ignition element at 250 megacycles. No numerical values were obtained since the losses were too small to measure. For frequencies below 1000 Mc, therefore, it is sufficiently accurate to ignore the base loss. A Bruceton test is conducted and a figure for system input power for 50% functioning obtained. Multiplication of the system input power by the system efficiency factor gives a calculated value for the power at the bridgewire. The value for calculated power to the bridgewire should remain essentially the same for all frequencies provided no factor other than bridgewire temperature causes initiation.

A valuable consequence of these studies was the evidence accumulated to show that stock radio frequency components (shorted stubs in particular) were not ideally suited to precision firing systems. This discovery resulted in extensive development of components, not originally contemplated in the scope of this project.

2. INVESTIGATIONS OF FIRING SYSTEM LOSSES

The accuracy of EED RF functioning sensitivity evaluation depends upon the degree to which it is possible to resolve the power delivered to the items being tested. Firing systems which feed known amounts of power into a matched termination will yield accurate results only if the hardware between the load (EED) and the point at which the power is introduced can be considered lossless. As these elements become lossy -- that is, as their dissipation of power becomes significant in relation to the power dissipated by the load -- the accuracy of resulting data is correspondingly reduced. However, if the amount of

power lost in these parts can be determined with certainty equal to that
associated with the measurement of input power, we can deduce the power
delivered to the EED with comparable accuracy.

A two-prong program was initiated early in the study to select
the most effective matching system and to specify its loss with reasonable
accuracy. Since the loss would probably be related to the magnitude of
the terminating impedance, we planned tests using UHF vacuum thermocouples
of varying resistance as loads to investigate low frequency losses. For
tests at higher frequency, above the limit for the thermocouples, we
employed thermal radiation detectors whose response was calibrated to
be proportional to the power dissipated in the bridgewire of the EED to
be evaluated.

2.1 Losses Determined by Use of Thermocouple Loads

Loss measurements on impedance matching devices were initially
restricted to the frequency range of 250 to 500 megacycles. The results
were to serve as a guide for an intelligent approach to the more difficult
range extending up to 1000 Mc, and beyond.

Stub stretchers, double stub tuners and triple stub tuners are
made up from various combinations of adjustable stubs and line sections,
and are almost universally employed for impedance matching at frequencies
above 200 megacycles. A line stretcher, which is an adjustable length
of coaxial line, is ordinarily inserted as a series component. An
adjustable stub is a variable length of coaxial line which is shorted
at one end and must of necessity be employed as a shunt. Open circuit
stubs are seldom used because of radiation problems at the open end.
These devices utilize the principle of combining series and shunt coaxial
impedance elements to produce a match between the load and source impedance.

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An experiment was designed to determine the relative losses of several types of coaxial matching devices. A double stub tuner, a stub stretcher and an assortment of line stretchers and shorted stubs were available for tests. Six coaxially mounted UHF vacuum thermocouples were employed as load terminations. The nominal values of dc heater resistance for these thermocouples are 50, 9, 2, 0.6, 0.4 and 0.2 ohms.

An additional experiment was designed to determine the amount of power delivered to each of the thermocouples without matching. Data from this experiment were used to calculate an unmatched voltage standing wave ratio (VSWR) for each thermocouple. The aim was to determine the correlation between the unmatched VSWR and the power delivered to the thermocouples when matched.

Details of this evaluation may be found in report Q-B1805-2. Figure 2-1 is included here to show the nature of the results. Of the several matching systems examined, the stub stretcher showed the least loss in these tests. The figure suggests that we may expect about 35% system losses for loads comparable to the MARK 1 MOD 0 (1.0 ohm) and 70 to 80% for the MARK 2 MOD 0 (0.1 ohm), in the 300 to 500 Mc frequency range.

The dotted curves included in Figure 2-1 indicate the nature of losses that would result if we failed to match these loads. From these data we determined an estimate of VSWR which was to be compared to that value computed on the basis of impedance measurements. However, when the impedance measurements were made it became apparent that the thermocouples' impedances at these higher frequencies were in no way similar to the impedances expected of the EED terminations. Accordingly it was presumed that the system loss data acquired in this manner could not be relied upon to give the needed accuracy. Emphasis was therefore shifted to examination of photodetector techniques.
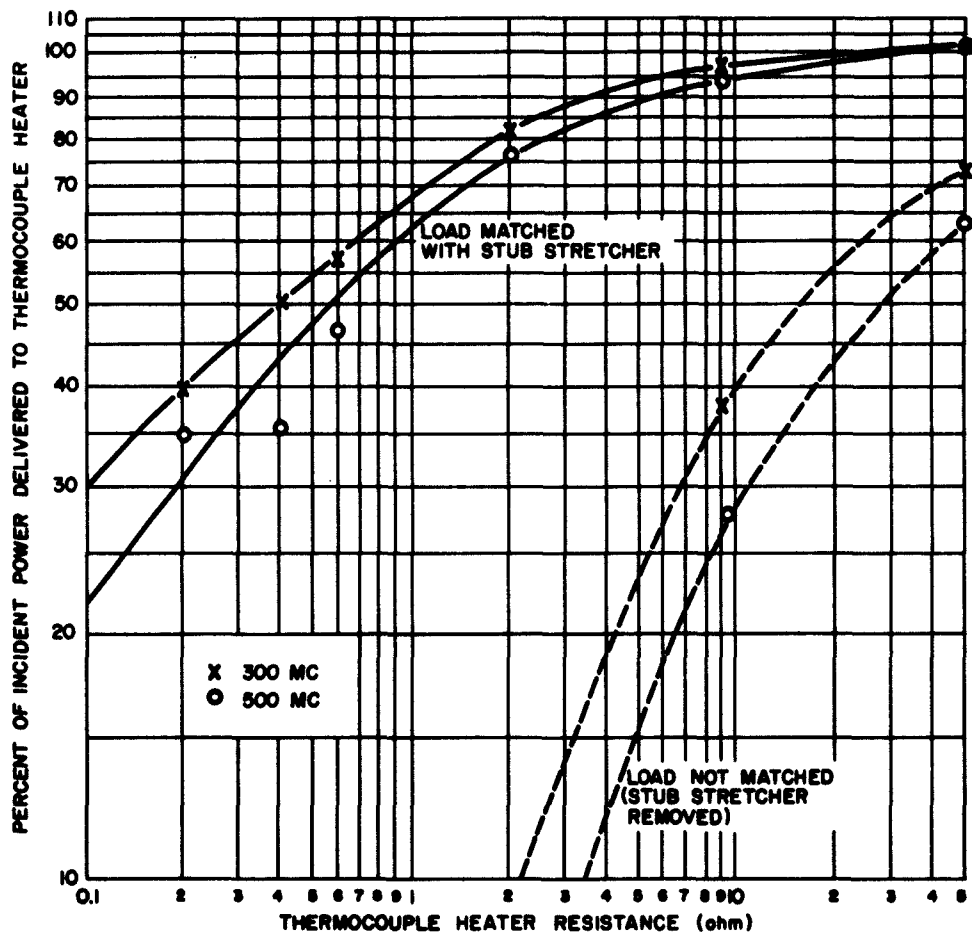
FIG. 2-1. PERCENT OF INCIDENT POWER INTO THERMOCOUPLE VERSUS
HEATER RESISTANCE (LOAD)

2.2 Infrared Detector Above a Bridgewire for Loss Determination

It appeared reasonable that an infrared detector mounted above and close to a heated bridgewire should have a response related to heat energy from the wire. It should make no difference whether the wire is energized by dc or RF power, if the wire has a small diameter and a length which is short compared with the wavelength of the applied RF energy. These assumptions were experimentally validated before this technique was accepted for use.

We know from the experience gained with thermocouple loads that matching losses could be made negligible at 250 megacycles for a load of approximately 50 ohms. On the other hand, we had been unable to prevent excessive losses when matching a 0.2-ohm load. Therefore, we could be reasonably certain that the method was sound if the detector above a 50-ohm wire provided equal indications for equal powers of dc and RF excitation.

The instrumentation was designed around a pair of Kodak Ektron infrared detectors, type N-1, mounted on a common heat sink to provide temperature compensation. One cell is exposed directly to a radiating source while the other is shielded.

The photo-conductive cells were connected as opposing arms of an ac resistance bridge with a 1000-cps excitation voltage. Relative output of the infrared detector is indicated by balancing the bridge and reading a calibrated dial.

The infrared detector mount provides a means for placing the cell in the best position relative to the bridgewire. One end of the device under test is installed in an adapter fitting for RF input. The other end, with the bridgewire exposed, is put into an opening in the detector mount.

As was previously mentioned, this measuring technique would be valid if equal amount of RF and dc power in a 50-ohm bridgewire would give equal output from the detector. A value of exactly 50-ohms could not be obtained; instead, a wire measuring 79 + j 16.5 ohms at 250 Mc was employed.

Several tests with the 79-ohm wire indicated an efficiency of 95 per cent at 250 megacycles. This efficiency was derived from the ratio of the dc power to the RF power required for unity output of the detector. Since some loss was expected when matching 79-ohms instead of 50-ohms, the figure of 95 per cent efficiency was considered to indicate a confirmation of the infrared method.

Additional tests were made with bridgewires having dc resistances of 0.28 and 0.40 ohms. The efficiency, using a stub stretcher, varied between 60 and 65 per cent. These tests were conducted with RF power of 300 milliwatts.

The system used in these preliminary experiments of photo-conductor techniques was not ideally adaptable to RF firing system requirements. However, indications were that the technique was feasible. While considering the needs for modifying the IR system to this new use it was decided to investigate other photoconductors such as the Clairex photoconductive cell. This cell was found to be more suited to the task of systems loss evaluation than were the cells tried first.

2.3 A Photo-Conductive Cell For Loss Determination

From a number of photoconductors a Clairex Type 404 photo-conductive cell whose spectral response peaks at 6900 angstroms, and is down 30 per cent at 6300 and 9000 angstroms, was selected. The cell was mounted in a light-tight aluminum cover, which was designed to be easily slipped on and off the firing mount.

We planned to operate the heated brigewire at a temperature just below the visible glow point. Because of the high output obtained from the cell at this temperature, an ordinary ohmmeter, such as a Triplett Model 630 multimeter, was adequate for initial output indication. The resistance of this Clairex cell decreases from more than 20 megohms when dark down to about 500 kilohms for the bridgewire temperatures involved in our tests.

We exposed the detector above a 50-ohm heater in a matched RF system to prove again that the method was valid. A length of high resistance wire was installed on a MARK 2 ignition element plug assembly (not on the 50-ohm line as was done in the previous experiment) in place of the low resistance bridgewire. The effective series RF impedance of this wire was 31-j 10.5 ohms at 250 megacycles.

The ignition element, with the 31-ohm bridgewire, was installed in the firing mount and matched with a stub stretcher at 250 megacycles. The ratio of the dc power to the RF power required for equivalent output of the photo-detector was 96.5 per cent. This was assumed to be near enough to 100 per cent to prove the technique was valid. We should expect a loss of at least 3.5 per cent with a load of 31-j 10.5 ohms.

This Clairex photo-cell and housing was used for all of the system calibrations performed in this study.

2.4 Evaluations of Losses Attributable
to the Squib or Ignition Element

The calibration procedure to be described in the following section assumes that the items to be tested have no inherent loss at the test frequencies. The total power entering the base of the items is, therefore, propagated to the bridgewire.

This assumption appeared to be valid since attempts to determine the loss associated with both the MARK 1 squib plug or the MARK 2 ignition element base gave indication of small power loss.

Attenuation measurements through the base of the MARK 1 MOD 0 squib were made at 250, 500 and 1000 megacycles and values between zero and 0.2 db were obtained. In some cases the 0.2 db value was for 250 megacycles, and the zero db figure was at 1000 megacycles. This indicates that the attenuation is too low to be determined by the measuring equipment.

Similar results were obtained for MARK 2 MOD 0 ignition elements. These were measured at 500 and 1000 megacycles only. No values higher than 0.1 db were recorded for the attenuation through the base of the ignition element.

In section 2.3, an efficiency of 96.5% at 250 megacycles was cited for an element with a 31-ohm bridgewire; this indicates that attenuation through the plug cannot be very great at that frequency. However, we wished to be certain that the greater part of the 3.5% power loss was not expended in the plug.

Reference to Figure 2-2 (a) will give some idea of the complexity of the various thin sections of dielectric materials in the base of the MARK 2 ignition element. A simulated element was constructed to have the same outside physical dimensions and bridgewire resistance as a standard MARK 2. Its losses were expected to be less than those of the standard because of the use of a polystyrene insulator in place of the thin nylon insulators and the mica washer. The dimensions were such that the characteristic impedance of the base is 50-ohms up to the point of bridgewire attachment. A drawing of this simulant is given in Figure 2-2 (b).

(a) Standard Mark 2 Mod O Element with Explosive and Part of Outer Case Removed

(b) "Lossless" Simulated Mark 2 Mod O Element
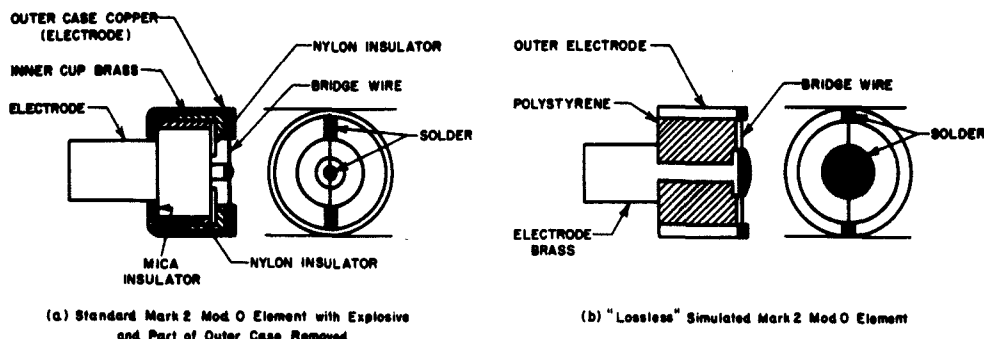
FIG. 2-2. COMPARISON OF STANDARD AND "LOSSLESS" MARK 2 MOD O IGNITION ELEMENT

The purpose of the unit was to serve as a reference for comparison with a group of standard MARK 2 ignition elements. Losses exhibited by the standard item could then be attributed to the base. At 250 Mc there was no significant difference between the two systems.

3. FIRING SYSTEMS AND INSTRUMENTATION DEVELOPMENTS

Results of our investigation into system losses led to consideration of means for their reduction, if not their total elimination. Accordingly a number of development efforts were initiated.

Though we had performed firing tests prior to the inception of this program, using stock RF components, we did so without the full realization of the magnitude of the losses thereby introduced. We had suspected that our systems were far from ideal, but not so far as the evidence accumulated in this program indicated to us. To effect an improvement, we designed a special adjustable shorted stub, and took every precaution to keep the length as short as possible, so that losses would be minimized.

Similarly we took especial care in designing mounts, to eliminate probable causes for loss. Selection and calibration of instrumentation, likewise, was made with an awareness of the rigorous demands of this totally new concept of precision firing. As a consequence, valuable knowledge was acquired, but more importantly, reliable systems became available and were used to perform RF firing evaluations with precision not previously obtainable.

3.1 Matching Systems

Our initial system loss evaluations (see Section 2) indicated that commercially available matching sections were responsible for unduly high system losses. Their chief drawback may be attributed to one or both of two shortcomings* in design: (1) The use of sliding contacts which either become dirty or lose their tension and thus give "high resistance" contact, or (2) because of the need for spring or finger contacts, the minimum stub length is unreasonably long. To offset these effects, we designed a unique shorted stub, which was the outgrowth of an arrangement assembled to fire one test at 250 Mc.

For the lower frequencies stub tuners become unwieldy, and it is necessary to resort to lumped parameter networks to perform the matching task.

3.1.1 A Novel Adjustable Shorted Stub

The novelty of our shorted stub lies first in the fact that it may be adjusted from 60 cm down to a length approaching zero and second in the unusual arrangement of collets which provide the actual short circuiting conductance across the line. A third feature is the provision of an external knob which allows the collets to be positively locked in any desired position. A micrometer adjustment for fine positioning is also included.

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*For our purpose they are shortcomings; for their ordinary intended use, the consequences may be not serious, and this may be an unjust accusation.

Figure 3-1 is a view of the adjustable shorted stub, partially disassembled to expose some of the inner constructional details. It consists basically of a 70-cm length of coaxial air line (outer and inner conductor) and an assembly containing the shorting slug which is inserted within the coaxial line. The 70-cm line is so constructed that it may be attached to the junction port of a coaxial tee fitting in such a way as to form a smooth continuation of the outer and inner conductors of the tee.

The shorting slug consists of two concentric silver plated collets. The outer collet has an internal taper which is a mating fit with the external taper of the inner collet. When the inner collet is drawn up into and flush with the outer collet, the locking action forces the contacting fingers against both the inner and outer conductor. The intimate contact between the tapered surfaces of the collets combines with finger-spreading collet action to create a plane of high conductance across the line at the junction of the coaxial tee. Figure 3-2 is a close-up view of the collets in the condition just described.

Figure 3-3 is a view of the completely assembled shorted stub with a section of adjustable air line attached for matching the MARK 1 MOD 0 squib at 250 megacycles. A longer adjustable line is shown just below the main assembly, and a short adjustable line at the bottom of the figure. These components can be interchanged as required.

3.1.2 An Expedient Shorted-Stub Adjustable Line Matching System

One attempt to solve an immediate matching problem was to assemble an adjustable line and a type "N" tee junction with a shorting cap screwed on one of the ports. This formed a simple stub stretcher with a fixed stub and an adjustable line. A trial showed that this "tuner" could almost match a MARK 2 ignition element inserted in the firing mount. A slight modification, to bring the shorting cap a little closer to the line junction, produced a match with a ratio of incident to reflected power of better than 200 to 1.
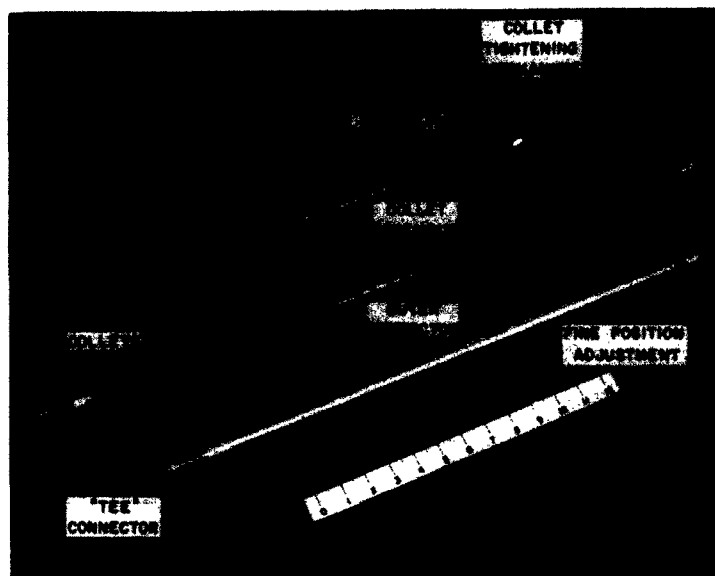
FIG. 3-1. ADJUSTABLE SHORTED STUB - DISASSEMBLED
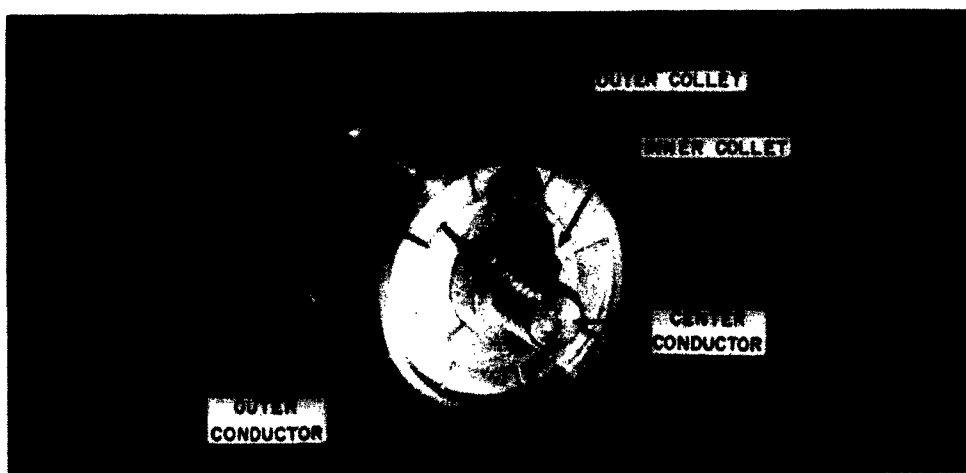
FIG. 3-2. CLOSE-UP OF COLLETS FOR ADJUSTABLE SHORT

COLLET TIGHTENING MECHANISM

POSITION ADJUSTMENT

ADJUSTABLE SHORTED STUB

ADJUSTABLE AIR LINE

COAXIAL "TEE"
CONNECTOR

A LONGER
ADJUSTABLE LINE

RF
INPUT

LOAD

A VERY SHORT LINE
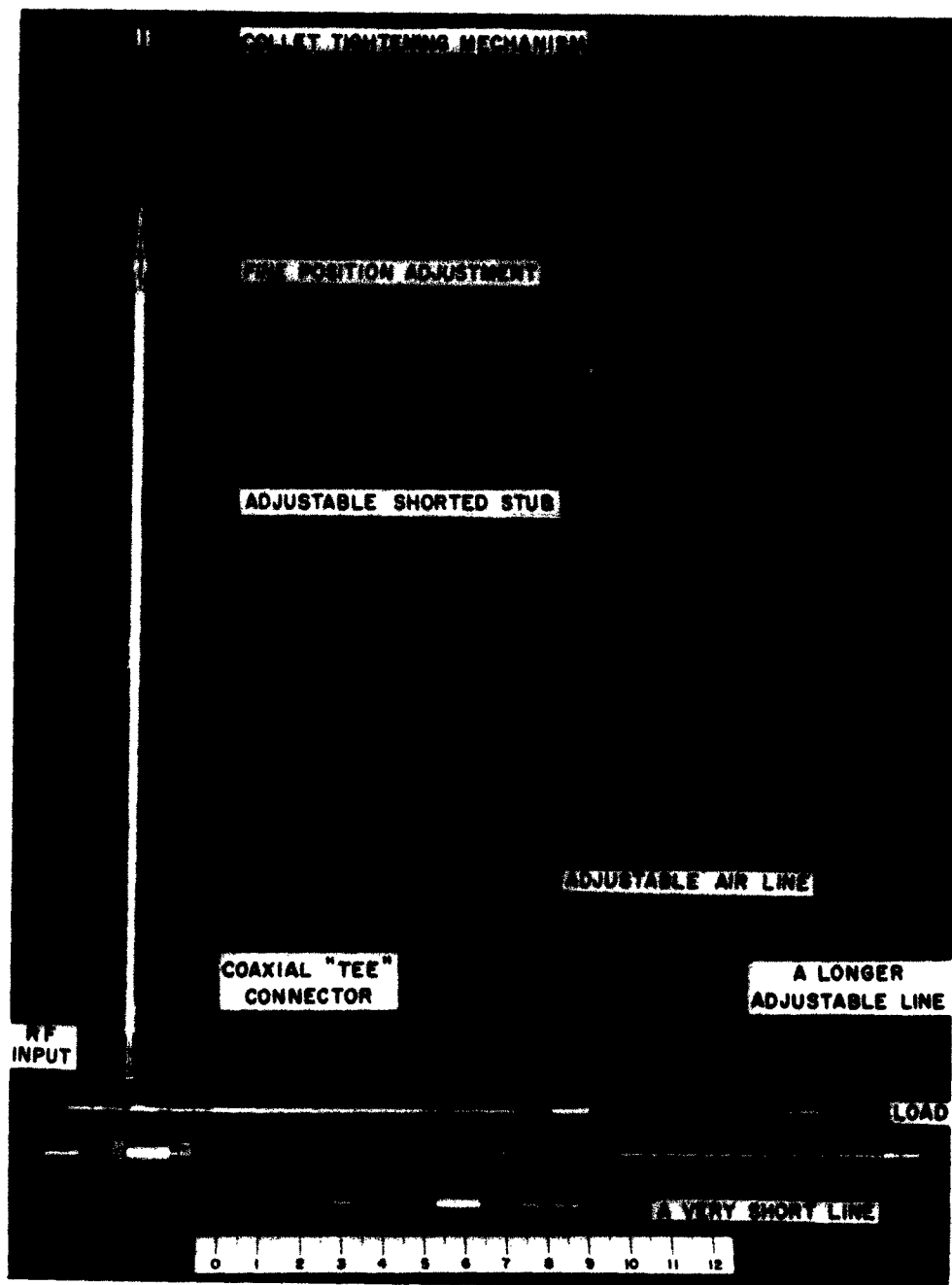
FIG. 3-3. MATCHING SYSTEM EMPLOYING THE SHORTED STUB AND
SECTIONS OF ADJUSTABLE AIR LINE

Tests with a number of ignition elements suggested that a fixed shorted stub and an adjustable line stretcher would produce an acceptable match for any of the MARK 2 ignition elements at 250 megacycles. Furthermore, the system appeared to be exceptionally stable compared with previous systems. Consequently this arrangement was used to fire the 250 Mc test of the MARK 2 MOD 0 ignition elements while the adjustable stub was being developed.

3.1.3 Low Frequency Matching Systems

At frequencies of 5 and 30 megacycles, impedance measurements show that we may assume that the real part of the impedance of the MARK 2 ignition element corresponds to the dc resistance of the bridgewire. The bridgewire, normally 0.1 ohms when cold, is about 0.14 ohms when heated to a dull red.

Figure 3-4 is a theoretical circuit for matching a MARK 2 ignition element to a 50-ohm line. The values of reactance required for matching were obtained by substitution in equations (3-1) and (3-2) .
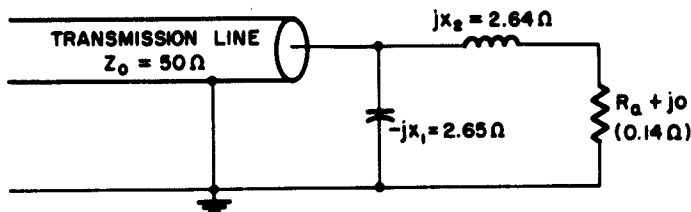
FIG. 3-4. THEORETICAL CIRCUIT FOR MATCHING MARK 2 IGNITION ELEMENT AT LOW FREQUENCIES

$$X_2 = \sqrt{Z_o R_a - R_a^2} \qquad (3-1)$$

$$X_1 = \frac{Z_o R_a}{X_2} \qquad (3-2)$$

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These equations yield almost equal values of 2.65 and 2.64 ohms for X_1 and X_2. At 5 megacycles, a capacitor of 0.012 microfarads and an inductor of 0.082 microhenries are required for the calculated reactances of 2.65 ohms. At 30 megacycles, the component values are 0.002 microfarads and 0.0136 microhenries.

The equations from which we calculated X_1 and X_2 assume that the load has no reactance. The load in Figure 2-2 is therefore denoted as $R_a \pm jo$ which in the case of the MARK 2 element is approximately 0.14 ohms. The net reactance of the load will modify the calculated value of X_2, however, this will not be considered here since the exact value of X_2 will be obtained empirically in actual practice.

Similar calculations were made to determine the theoretical values of components required for matching the MARK 1 MOD 0 squib at 5 and 30 megacycles. The nominal dc resistance of the squib bridgewire is 1 ohm (cold) and about 1.4 ohms when heated to a dull red. The calculated values for X_1 and X_2 are 8.49 and 8.24 ohms respectively. At 5 megacycles, these reactances may be obtained with a capacitor of 0.00375 microfarads and an inductor of 0.262 microhenries. At 30 megacycles, these values become 0.000625 microfarads and 0.0436 microhenries.

The matching networks used in the firing of the squib and ignition elements were simple combinations of inductive and capacitive elements mounted in an aluminum box as shown in Figure 3-5. Here can be seen a variable 1000-picofarad tuning capacitor, a fixed shunt capacitor, and a series tuning inductor. The fixed capacitor and the series inductor are removable so that other values may be substituted according to the frequency and the impedance of the item under test.

It would ordinarily be assumed that both the series inductor and the shunt capacitor would have to be variable in order to allow for the normal variation in resistance and reactance of the EED being tested. However, it was found that the MARK 1 MOD 0 squibs and the MARK 2 MOD 0
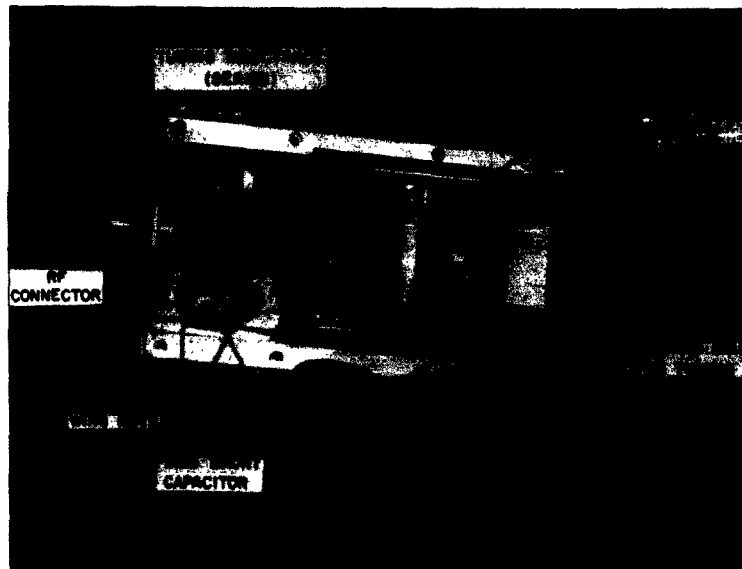
FIG. 3-5. A TYPICAL LUMPED ELEMENT MATCHING NETWORK

ignition elements were so uniform in their electrical characteristics
that a fixed inductance and capacitance in combination with a single
variable capacitor was enough to produce an acceptable match for any
individual in a group under test.

3.2 Firing Mounts

The mount which adapts the EED to the RF line is not the
least important part of the system. Mount designs must insure repeatability
of mounting EED's so that no variation in results can be attributed to
deficiencies at this point. Reliable contact between leads and line
conductors must also be assured. It is for this latter reason as well
as to make provision for insertion of a voltage probe, that a redesign
of the mount initially constructed for this test schedule was required.

Figure 3-6 shows a cross section of the mount finally used to perform the tests reported herein. Unique features of this mount include a collet arrangement to insure a positive electrical contact between the outer case of the ignition element and the body of the mount. Figure 3-7 shows this feature more clearly. The MARK 2 ignition element with the bridgewire exposed can be seen held by the collet.

A voltage probe can be inserted to make contact with the center conductor, at a point close to the base of the element. The probe is removable, and a plug closes the opening during actual firing. The probe was used for trials to measure power at the input to the EED, by a voltage-impedance method.

A series of adaptor parts permit this mount to accept the MARK 1 MOD 0 squib. These are shown in Figure 3-8. The leads of the squib must be cut to exact length and shaped before installation in the mount. This is done with a special holding and stripping device, not shown. A cut and dressed squib is in the foreground of the picture, which also shows another squib mounted in the center conductor. A socket-head screw is turned to fasten one of the leads in the center conductor. A slot is provided in the collet to force the ground lead against the bottom edge of the outer case of the squib. The collet-closer brings the collet into intimate contact with the bottom circumference of the squib case. The screw that tightens the center conductor is reached by a special wrench inserted through a hole in the main body of the mount. The complete assembly with squib in place is shown in Figure 3-9.

3.3 Output Indicator And Power Supply for Clairex Cell

A Triplett multimeter, Model 630, may be used for indication of the resistance of the Clairex 404 photocell. When set on the X100,000 ohms scale, this meter indicates 500,000 ohms mid-scale. With the Clairex cell about 1/16-inch above a squib or ignition element bridgewire

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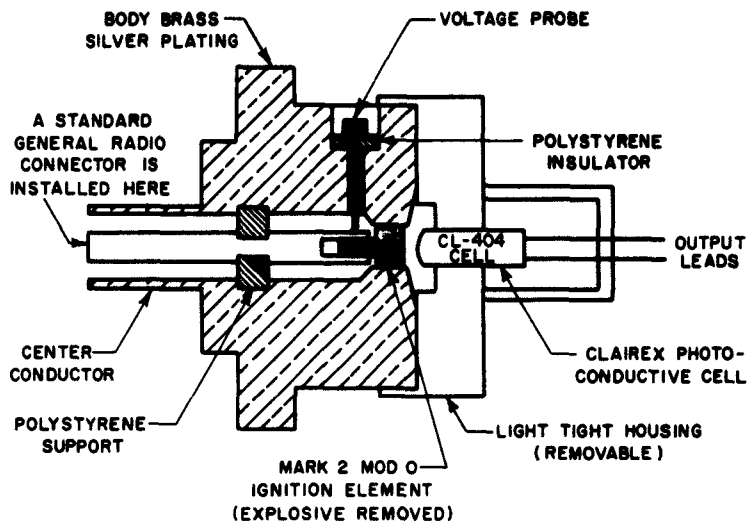
FIG. 3-6. CROSS-SECTION OF MARK 2 MOD 0 FIRING MOUNT
(Photocell Housing Attached)
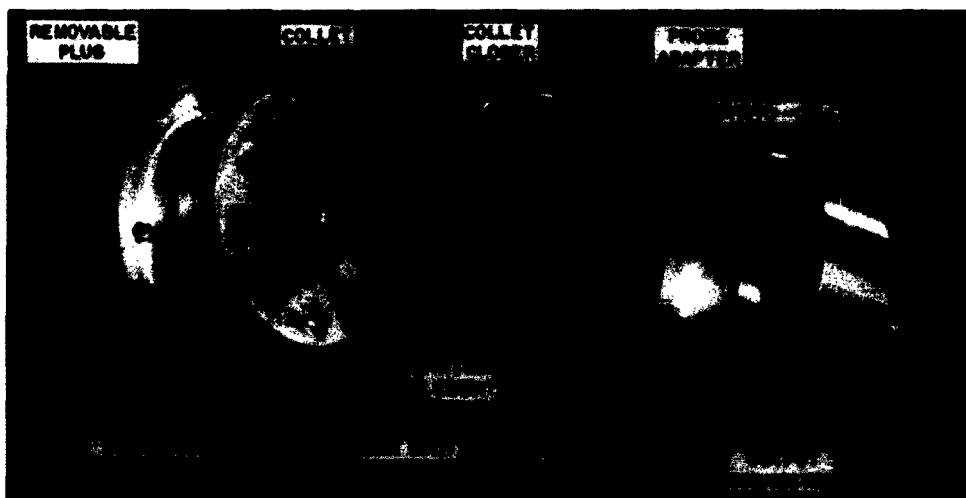
FIG. 3-7. FIRING MOUNT AND PHOTOCELL HOUSING

- 19 -
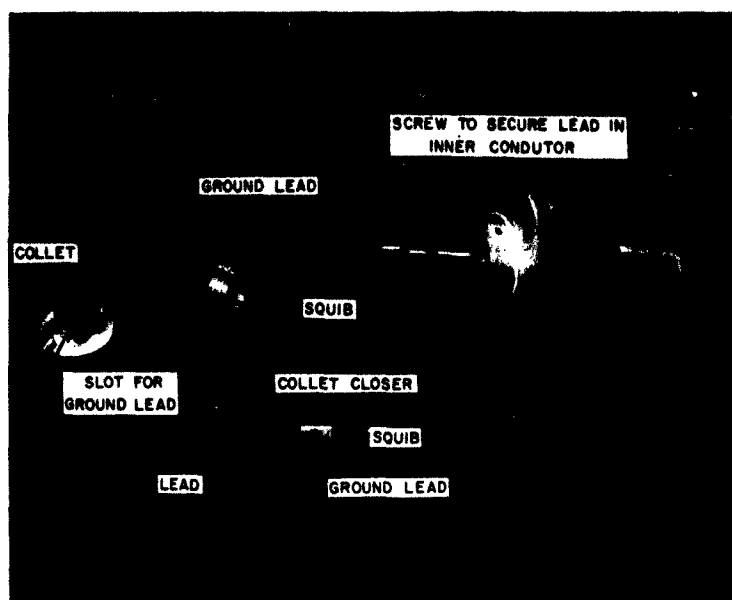
FIG. 3-8. ADAPTER PARTS FOR ACCOMMODATING MARK I MOD O SQUIB
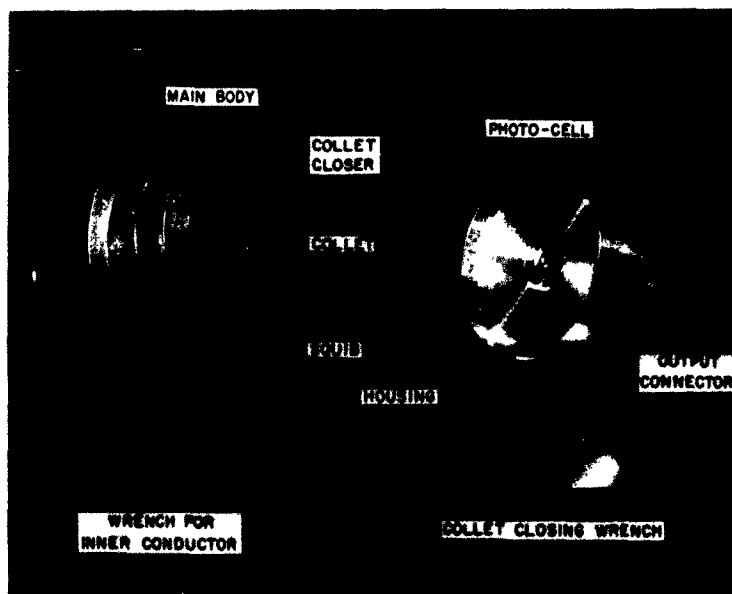
FIG. 3-9. FIRING MOUNT AND PHOTOCELL HOUSING
(Adapted for Mark I Mod O Squib)
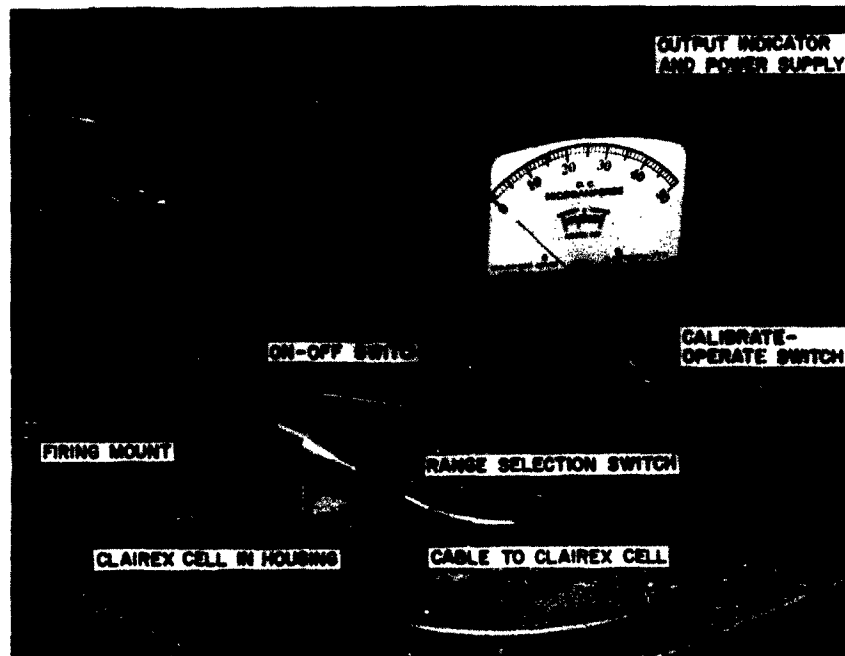
FIG.3-10. CLAIREX CELL OUTPUT INIDICATOR AND POWER SUPPLY

this would correspond to a dull red glow of the bridgewire. Anticipating the need for greater sensitivity, we developed an improved meter system.

Initial firings indicated that the 50% fire level could be considerably below a dull red glow of the bridgewire. To facilitate tests at these lower power levels, we designed a combined photocell power supply and output indicator, specifically for use with the Clairex cell. Figure 3-10 is a view of this instrument. A photocell in a housing attached to the firing mount can be seen connected to the instrument by a shielded cable. A seven-inch 50-microampere meter is used as an indicator. Although the instrument functions as a high resistance ohmmeter, there is no necessity for calibrating the scale in ohms. The original calibration of the scale combined with observation of the range dial setting (1 to 10) is all that we need. Description of the electronic circuit follows.

FIG. 3-11. SCHEMATIC DIAGRAM—CLAIREX CELL OUTPUT INDICATOR AND POWER SUPPLY

When the multimeter is used and set to the X100,000 ohm resistance scale, a 30 volt battery, an indicating meter, and a series resistor to limit current to 60 microamperes constitute the essential elements of the circuit. Such a circuit can be made to measure higher values of unknown resistance if the battery voltage is increased to say, 90 volts, and the series resistance increased accordingly.

The instrument we designed to replace the multimeter is essentially a regulated power supply and an ohmmeter circuit. Details of the circuit are shown in the schematic diagram Figure 3-11. The regulated power supply is a conventional supply with an OB2 gas-tube voltage regulator. The output across this tube is approximately 107 volts. R_3 is a series rheostat, which is adjusted to give a voltage drop of exactly 100 volts across the precision voltage divider R_4 to R_{13}.

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The voltage divider, consisting of ten precision wirewound resistors of 500 ohms each, draws a constant 20 milliampere current from the 100 volt supply. Voltages from 10 to 100 volts, in steps of 10 volts, are selected by the range switch S_2. Series resistors R_{14} to R_{23} are so chosen as to cause the "calibration" current to be 50 microamperes at each range. When the switch S_3 is thrown to "Calibration Check" position, the Clairex cell is shorted out and the meter will read 50 microamperes $\pm$ 1% on all ranges. The first range position, S_2 set to R_{23}, is considered to be the reference position. R_3 is adjusted so that the meter reads exactly 50 microamperes or full scale when S_3 is on CAL. check and the range switch is on range 1. All other ranges will then be automatically adjusted to within 1%, which is the tolerance of the resistors used.

The value of 20 milliamperes for the current through the voltage divider was chosen to provide a maximum loading effect of 0.4% when the meter is indicating over the range of zero to 50 microamperes.

Voltage ranges of 10 to 100 volts in steps of 10 were chosen in place of normal scales 1X, 10X, 100X, etc., because steps of 10 volts are more practical for our special application. When used on the highest range, the meter is capable of indicating bridgewire heat about 40% below a dull red glow. The meter will then indicate at about mid-scale or 25 microamperes. This unit is a considerable improvement over an ordinary multimeter for indication of photocell resistance.

3.4 Calorimetric Power Reference Source

A Hewlett-Packard Model 434A calorimetric power meter was obtained as an RF reference standard for this program. This meter was selected for several reasons. First, it has several ranges, from 10 mw full scale to 10 watts full scale. The power levels at which the MARK 1 MOD 0 squib and the MARK 2 MOD 0 ignition element are expected to fire should fall within these ranges.
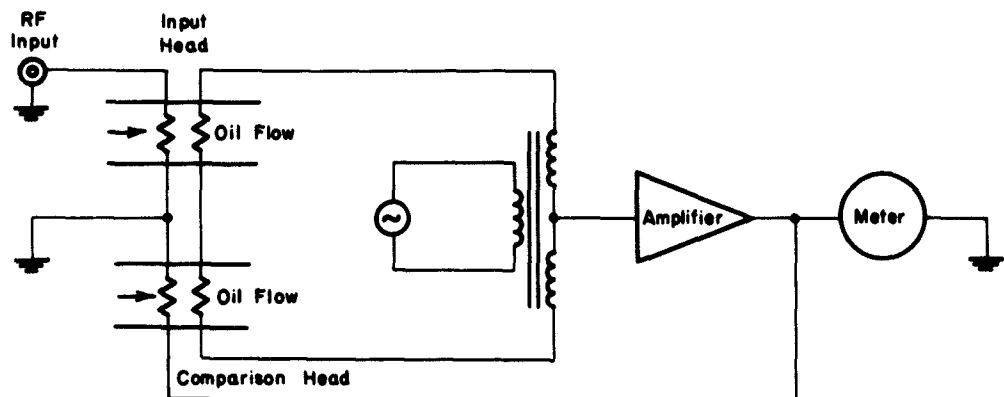
FIG. 3-12. SIMPLIFIED CIRCUIT OF HP MODEL 434A CALORIMETRIC POWER SUPPLY

Second, the calorimetric power meter can be calibrated simply by substituting an equivalent dc power for the RF power. This dc power can be accurately measured with instruments whose calibration is certified by the Bureau of Standards. The overall accuracy of the calorimeter can be held within ± 2% of the full scale reading when special calibration techniques are employed.

Basically, the 434A power meter consists of a balanced bridge circuit which becomes unbalanced when applied RF power heats one branch, An error voltage produced by this unbalance is amplified and fed back to the bridge, bringing it back into balance. Figure 3-12 shows a simplified diagram of the power meter's circuit. The input head consists of a 50-ohm resistive termination for the RF input and a thermistor, which is a temperature sensitive resistor in close proximity. A flow of oil over these elements maintains them at the same temperature. The comparison head is constructed in the same way. The temperature sensitive resistors are in adjacent legs of an audio frequency bridge circuit. RF power, when dissipated in the terminating resistor, will raise the

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temperature of the thermistor, causing the bridge to become unbalanced.
An error voltage, produced by this unbalance, is amplified and fed back
into the comparison head load resistor. The power dissipated in this
resistor causes the bridge to become balanced. A meter movement is
connected to this feedback circuit and is deflected by an amount pro-
portional to the power required to rebalance the bridge. To eliminate
zero drift and maintain stability, the oil flowing in the input and
comparison heads is passed through a heat exchanger prior to entering
the heads. This maintains both heads at the same temperature initially.
A series flow system is used so that the flow rates in the heads are
identical.

A 100 mv ± 1% dc power supply is provided with the calorimeter.
When the instrument is calibrated with this supply the overall accuracy
of the instrument is within ± 5% of full scale. This error includes
RF and calibration losses but does not include mismatch losses which
might occur between the system being evaluated and the RF input head.
The accuracy of the power meter can be greatly improved by calibrating
at the same level as the RF power to be measured. In this way the
power meter serves only as a transfer instrument and errors due to dif-
ferences in range settings and meter tracking errors are eliminated.
To do this a variable dc power supply of high stability is necessary.
The power produced by this supply may be accurately measured by the
following technique.

The RF input termination resistor, with a nominal value of
50 ohms, may differ from this by as much as ± 5 ohms. A calculation
of power based on the input voltage and the load resistor would, therefore,
be in considerable error unless the value of this resistor were accurately
measured at each input power level. The error produced by changes in
this resistor may be reduced greatly by the following method. A precision
50 ohm resistor (R_s) is placed in series with the load resistor (R_L) as

shown in Figure 3-13. The voltage
is now measured across the series
combination of the two resistors.
Power dissipated in the load (R_L)
may now be computed as follows:

$$P_L = \frac{E_L^2}{R_L} \tag{3-1}$$
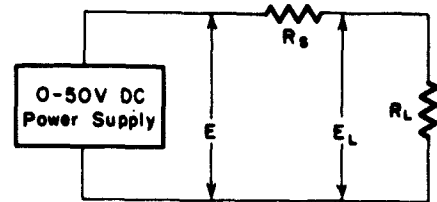
FIG. 3-13. DIAGRAM OF CALORIMETER

CALIBRATOR CIRCUIT

and

$$E_L = E \frac{R_L}{R_s + R_L} \tag{3-2}$$

therefore

$$P_L = E^2 \frac{R_L}{\left(R_s + R_L\right)^2} \tag{3-3}$$

The change in load power (P_L) as R_L changes from 40 to 60 ohms is plotted
in Figure 3-14. As indicated in the plot, a change in R_L of $\pm$ 5 ohms
from the nominal value of 50 ohms changes the power dissipated in R_L by
less than 0.3%. Therefore, to measure P_L, accurately, all we need do is
measure the voltage across the series combination and compute the power
from equation 3-3, using the nominal value of R_L, since changes in this
resistance produce negligible error. However, since the power is a func-
tion of the voltage squared, this voltage must be measured to an accuracy
twice that of the accuracy required for P_L. By employing a precision
potentiometer calibrated against a standard cell we should be able to
compute the dc calibration power to within $\pm$ 1%.
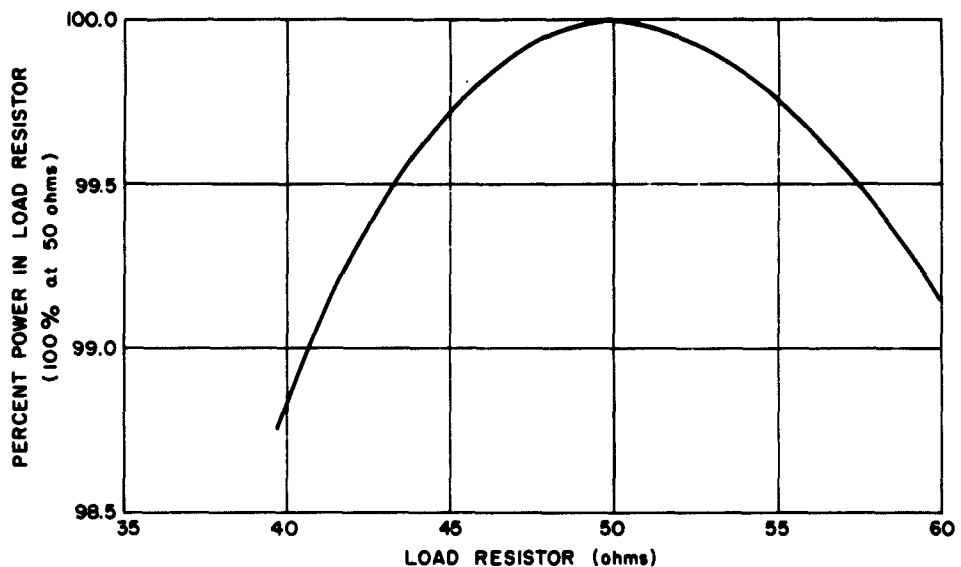
FIG.3-14. CHANGE IN LOAD POWER FOR CHANGE IN LOAD RESISTANCE

4. DETERMINATION OF SYSTEM LOSS FACTOR; SYSTEM CALIBRATION

The total power entering a completely matched RF system can be accurately measured by conventional means. The RF power arriving at the exposed bridgewire of an EED can be detected as explained in Section 2.3. If there is no significant attenuation caused by the base of the element, we may reasonably assume that the system loss is equal to the total power entering the system minus the power absorbed in the bridgewire.

System calibration is, therefore, performed on the equipment after it is assembled in preparation to fire the test. Figure 4-1 shows the general form of our firing systems; although the physical character of the separate components may vary with frequency, their function remains fixed. The procedure for calibration is as follows:
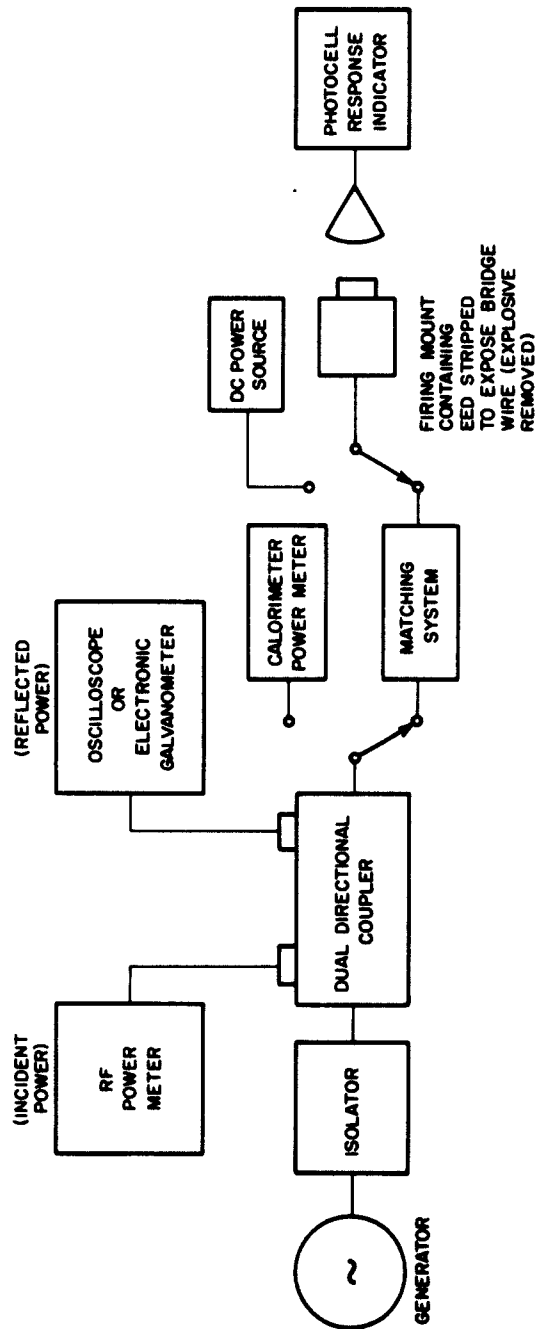
FIG. 4-I. BASIC ARRANGEMENT FOR FIRING SYSTEM CALIBRATION

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A number of EED's from the lot to be evaluated are stripped
of their explosive charge to expose the bridgewire. One of these is
mounted as a termination, with the photocell fixed to respond to the
bridgewire illumination. The matching section is adjusted to give the
best possible match, indicated by a minimum deflection of the galvanometer
which responds to the reflected power out of the dual directional coupler.
RF power is then adjusted to give a reasonable photocell indication
(500 Kilohm, read by the multimeter, was standard for all calibrations
made in this series). The magnitude of this RF power is determined by
switching the generator output into the calorimeter power meter. The
firing mount and photocell fixtures are then removed from the RF system
and connected to a dc power source. DC power, measured by use of a
Leeds and Northrop K-2 potentiometer, is adjusted to give the same
photocell response as was noted for the RF input (500 Kilohms). The
ratio of the RF to dc power magnitudes averaged for the number of EED's
prepared for this purpose is taken as the system calibration (efficiency)
factor.

Table 4-1 gives the results of system loss factors determined
for ignition elements intended for use in this series of tests. The
data from which these values are obtained are included in Appendix A.

Table 4-1

SYSTEM LOSS FACTORS

Frequency (Mc)	System Loss Factor	
	MARK 1 Squib	MARK 2 MOD 0
5	0.948	0.696
30	0.718	0.449
250	0.810	0.412
1000	0.514	0.560

As stated earlier, the same basic system was used for each calibration. Why then are not the loss factors identical? First, because the matching system for 5 and 30 Mc is a lumped parameter network, whereas that for 200 and 1000 Mc is the stub and line-stretcher tuner. Second, for any system we would expect the loss to increase as frequency is increased, and as the load impedance departs from 50 ohms. Except for the MARK 2 MOD 0 loss factor at 1000 Mc, the data bear out these expectations.

5. RF SENSITIVITY TESTS OF MARK 1 SQUIB AND MARK 2 IGNITION ELEMENT

Both the squib and the ignition element have been evaluated for sensitivity at frequencies of 5, 30, 250, and 1000 Mc. Tests were run in accordance with the Bruceton Plan,[1] and 100 of the devices were expended in each test to insure a reasonable confidence level. The sample group of each item was taken from a single production lot. Two large lots one of each item, were selected, so as to avoid the chance of a wide lot-to-lot deviation.

The firing systems were carefully calibrated for system efficiency as discussed in the previous section. Accordingly, data are given as input power to the bridgewire for various probabilities of functioning. On the assumption that power loss in the base of the element is negligible within the frequency span of the tests, we may construe the data to be equally representative of power input to the base of the element. Recognizing that the loss of the base plug will become more significant as frequency increases, we are led to be moderately suspicious of the data given for 1000 Mc.

Results of the firing evaluations are given in Table 5-1; raw data and calculations are appended. The appearance of two sets of data for MARK 2 MOD 0 elements evaluated at 30 Mc warrants some explanation. Those results tabulated at the bottom of the table were obtained first.

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(1) For a description of the Bruceton Plan and the manner in which data are reduced therefrom see: AMP Report No. 101.12 "Statistical Analysis for a New Procedure in Sensitivity Experiment," July 1944.

Table 5-1

RF SENSITIVITY OF MARK 1 MOD 0 SQUIB AND MARK 2 MOD 0 IGNITION ELEMENT

ITEM	Frequency (Mc)	System Input Power (watts) For Indicated (%) Probability of Functioning					System Calibration Factor	Calculated Input Power (watts) To Bridgewire For Indicated (%) Probability of Functioning				
		0.1	1.0	50	99	99.9		0.1	1.0	50	99	99.9
MARK 1 MOD 0	5	0.0652	0.0718	0.0966	0.1299	0.1431	0.9479	0.06180	0.06806	0.09157	0.1231	0.1356
	30	.0812	.0903	.1250	.1732	.1925	.7177	.05828	.06481	.08971	.1243	.13816
	250	.0714	.0798	.1134	.1584	.1771	.8100	.05783	.06464	.09185	.1283	.1434
	1000	.1398	.1472	.2008	.2740	.3080	.5139	.07184	.07564	.1032	.1408	.1583
MARK 2 MOD 0	5	1.024	1.070	1.226	1.404	1.467	.6962	.7129	.7449	.8535	.9775	1.021
	30	1.504	1.599	1.937	2.345	2.495	.4491	.6754	.71833	.8699	1.053	1.121
	250	1.451	1.599	2.165	2.930	3.231	.4121	.5979	.6589	.8922	1.207	1.332
	1000	1.158	1.207	1.372	1.560	1.636	.5604	.6489	.6762	.7689	.8741	.91681
	30(1)	1.762	1.861	2.205	2.613	2.760	.4226	.7446	.7865	.9318	1.104	1.166

(1) Evaluation test using wrong lot of elements

A comparison of the 50% level to other data which was available at the
time indicated a difference much greater than had been anticipated.
A study led to the discovery that the items used in this test were
inadvertently taken from a second lot of elements in storage. Repeating
the test with devices from the lot reserved for this program produced
the data tabulated in its proper order. These two sets of data indicate
the order of magnitude of the lot-to-lot variations that were eliminated
from our results by working with a single lot.

Calculations made with dc firing data indicate that the mean
firing (50%) level for the MARK 1 squib and the MARK 2 ignition element,
expressed as power, should be 0.09 and 0.9 watts respectively. The
results of calculated power to the bridgewire given in Table 5-1 confirms
our long-held belief that the inherent (bridgewire mode of power application)
sensitivity of a hot-wire bridged device is adequately defined by its
dc sensitivity for frequencies below 1000 Mc. As frequency is increased
beyond this point we can expect a significant difference between RF and
dc power sensitivity. The data at 1000 Mc determined in this program,
particularly that for the MARK 2 MOD 0 ignition element, indicate that
differences between RF and dc sensitivity may, for some devices, show
up at a lower frequency.

Evaluations at frequencies up to and including 10,000 Mc were
initially planned to be a part of this program. However, technical
problems had to be resolved to allow power at the input of the device to
be measured with a precision comparable to that of the data already
presented. It became apparent that these solutions could not be obtained
under the limitations of the present program. Consequently no firings
above 1000 Mc were performed. The data for the sensitivity of the MARK
2 MOD 0 ignition element must therefore be accepted at face value only.
No plausible explanation can be given for its deviation until firings
performed at higher frequencies are available to establish a trend.

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6. CONCLUSIONS AND RECOMMENDATIONS

With the completion of Bruceton tests at 5, 30, 250 and 1000 megacycles, we are in a position to draw limited conclusions regarding the sensitivity of the MARK 2 ignition element. The loss in the base of this item is considered to be negligible at frequencies of 1000 megacycles and below. Therefore, the figure obtained for sensitivity at the bridgewire is the sensitivity at the base of the item. The average sensitivity of the MARK 2 element over the range of 5, 30, 250 and 1000 megacycles is, then, 0.893 watts. This figure corresponds very closely with the dc firing level, which for a 10 second pulse is 0.9 watts.

Bruceton tests have also been completed for the MARK 1 MOD 0 squib at these same frequencies. The loss in the base of the squib using negligible, we may give a tentative figure of 0.0910 watts for the sensitivity of this item. The equivalent dc sensitivity of this item, 0.09 watts, is as we would expect very close to the RF value.

While a considerable part of the original aims of the program were accomplished, several unforeseen complications arose during the study. It should be understood, that the attention given these complications has in nearly every case further extended the present state of knowledge in this field. These complications can be divided into two major categories; RF power detection at the base of the EED, and impedance matching.

With regard to power detection, it was indicated from the preliminary studies that vacuum thermocouples of varying resistances could be used to obtain a calibration of the system losses as a function of terminating resistance. However, while this still remains a possibility, it was found that the mounted thermocouples represented impedances that were so different from the actual EED's that it was decided to go to a different system. We now use for the lower frequencies

a photo detector which detects the energy dissipated in the bridgewire.
This system works very well at the lower frequencies, but is valid only
as long as the RF energy is dissipated entirely in the bridgewire and there
is no direct RF interaction with the detector. Both of these points are
questionable at high frequencies.

The more direct and most useful approach to this problem is to
determine the power directly at the base of the plug. However, this is
more difficult to do, but additional study should lead to practical
solutions.

With regard to matching techniques, great strides have been
made. It was determined during this study that system losses are almost
entirely functions of the degree of mismatch between the generating
system and the termination, and the physical length of the system from
the matching device to the EED. For the tremendous mismatches which
normally occur between a typical 50 ohm system and an EED these losses
can become quite large; so large in fact, that situations can occur which
make it impossible or extremely difficult to obtain a match. A limited
theoretical development indicated that present commercially available
matching systems were not adequate and pointed out the necessary direction
in which to go to develop more effective matching devices. These devices
have subsequently been developed and proven in use. This then brings us
to the final status of the contract. At this time the following items have
been accomplished.

a). Development of precision firing instrumentation for
all four frequencies (5, 30, 250, 1,000 Mc) applicable
to hot-wire bridged EED's having negligible loss in
their base.

b). Development of system loss calibration techniques for
this same frequencies, and actual calibration of these
firing systems.

c). Development of refined matching systems for the
frequencies stated.

d). Successful precision firing tests for both the MARK
1 MOD 0 squib and the MARK 2 MOD 0 ignition element
at the frequencies stated.

Included in the scope of this contract, but not completed,
were tests at 3 and 10 Gc. Because of the great number and complexity of
problems that arose during the performance of the work documented herein,
it was not possible to perform these tests within the limitations of this
program. Additional problems requiring more intensive study than could
be supported by this program were envisioned. It was concluded, therefore,
that these would be deferred to a subsequent investigation.

On the other side of the balance, the solutions to the many
unpredicted problems encountered in this investigation have yielded
knowledge of considerable future value.

Though much has been learned during the performance of this work
still more is to be learned. Means to provide this same sort of reliable
test data at 3 and 10 Gc (or higher) must be developed. Likewise, in
view of the evaluations of "RF protected" squibs and fixes, some thought
must be given to the manner in which these will necessitate altering the
technique proposed in this document.

Finally, many areas of potential hazard have been seemingly
ignored in this study. Some thought should be given to "precision
firings," to determine the sensitivity of EED's to: (1) pulsed RF signals,
(2) lead-to-case functioning, and (3) plug heating leading to cook-off.
More important than the mere evaluation of these functioning modes is the
thought of investigating their interrelation one to another. Some evidence
gained in years of RF testing suggests that pulsed signals of average power
content much less than that required of a dc signal can induce a
functioning of some EED's. To know why and how this is accomplished (if
it is indeed so, and not merely an unwarranted conclusion) is to have
knowledge of significant application to the HERO effort.

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ACKNOWLEDGEMENTS

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Major portions of this report were prepared by these men cited in proportion to their contribution to the productive effort.

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APPENDIX A

SYSTEM CALIBRATION DATA

A

Table A1

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 5 MEGACYCLES

Squib Number	RF Power Input Prf (Watts)	Light Cell Resistance (Ohms)	DC Calibration with L & H "G" Pot E_R (volts)	E_H (volts)	R_S (ohms)	Heater Current $I_H = \dfrac{E_R}{R_S}$ (amp)	Heater Power (dc) $Pdc = E_H \times I_H$ (Watts)	RF system Efficiency $= \dfrac{Pdc}{Prf}$	RF Freq. (Mc)
7	0.182	500K	0.34586	0.49772	1	0.34586	0.172141	0.9458	5
6	0.178	500K	0.33797	0.49626	1	0.33797	0.167720	0.9422	5
5	0.181	500K	0.34061	0.50291	1	0.34061	0.171296	0.9464	5
4	0.181	500K	0.34511	0.50423	1	0.34511	0.174015	0.9614	5
3	0.178	500K	0.33649	0.50259	1	0.33649	0.169117	0.9501	5
7	0.180	500K	0.34405	0.49336	1	0.34406	0.169740	0.9430	5
6	0.180	500K	0.33852	0.49773	1	0.33852	0.168491	0.9361	5
5	0.180	500K	0.33992	0.50045	1	0.33992	0.170112	0.9451	5
4	0.182	500K	0.34431	0.50379	1	0.34431	0.173459	0.9531	5
3	0.181	500K	0.33875	0.51078	1	0.33875	0.173027	0.9559	5

Highest Efficiency = 0.9614
Average Efficiency = 0.94791
Lowest Efficiency = 0.9361

A1

Table A2

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 30 MEGACYCLES

Squib Number	RF Power Input Prf (Watts)	Light Cell Resistance (Ohms)	DC Calibration with L & N "K" Pot. E_R (volts)	E_H (volts)	R_S (ohms)	Heater Current $I_H = \dfrac{E_R}{R_S}$ (amps)	Heater Power (dc) Pdc = $E_H \times I_H$ (watts)	RF system Efficiency $= \dfrac{Pdc}{Prf}$	RF Freq. (Mc)
5	0.235	500K	0.34192	0.50351	1	0.34192	0.17216	0.7326	30
4	0.238	500K	0.34775	0.50446	1	0.34775	0.17542	0.7370	30
3	0.251	500K	0.34245	0.51479	1	0.34245	0.17629	0.7023	30
2	0.249	500K	0.33300	0.51527	1	0.33300	0.17158	0.6890	30
1	0.242	500K	0.33954	0.49101	1	0.33954	0.16669	0.6888	30
5	0.242	500K	0.34396	0.50726	1	0.34396	0.17448	0.7209	30
4	0.240	500K	0.34786	0.50611	1	0.34786	0.17605	0.7335	30
3	0.248	500K	0.34242	0.51466	1	0.34242	0.17623	0.7106	30
2	0.235	500K	0.33222	0.51539	1	0.33222	0.17122	0.7370	30
1	0.232	500K	0.34027	0.49559	1	0.34027	0.17216	0.7326	30

Highest Efficiency = 0.7370
Average Efficiency = 0.7177
Lowest Efficiency = 0.6888

Table A3

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 250 MEGACYCLES

Squib Number	RF Power Input Prf (Watts)	Light Cell Resistance (Ohms)	DC-Calibration with L & N "K" Pot E_R (volts)	E_H (volts)	R_S (ohms)	Heater Current $I_H = \dfrac{E_H}{R_S}$ (amps)	Heater Power (dc) $Pdc = E_H \times I_H$ (Watts)	RF system Efficiency $= \dfrac{Pdc}{Prf}$	RF Freq. (Mc)
7	0.212	500K	0.34564	0.49647	1.0	0.34564	0.17159	0.8094	250
6	0.208	500K	0.34066	0.50206	1.0	0.34066	0.17103	0.8222	250
5	0.207	500K	0.34195	0.50477	1.0	0.34195	0.17261	0.8338	250
4	0.217	500K	0.34483	0.50424	1.0	0.34483	0.17387	0.8013	250
3	0.217	500K	0.33812	0.50806	1.0	0.33812	0.17178	0.7916	250
7	0.214	500K	0.34457	0.49326	1.0	0.34457	0.16996	0.7942	250
6	0.208	500K	0.33822	0.49642	1.0	0.33822	0.16789	0.8072	250
5	0.209	500K	0.34085	0.50125	1.0	0.34085	0.17085	0.8175	250
4	0.214	500K	0.34346	0.50045	1.0	0.34346	0.17188	0.8032	250
3	0.212	500K	0.33963	0.51138	1.0	0.33963	0.17368	0.8192	250

Highest Efficiency = 0.8338
Average Efficiency = 0.80997
Lowest Efficiency = 0.7916

A3

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Table A-4

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 1 MOD 0 SQUIB AT 1000 MEGACYCLES

Squib Number	RF Power Input P_{rf} (Watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot E_R (Volts)	E_H (Volts)	R_S (Ohms)	$I_H = \dfrac{E_R}{R_S}$ (Amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $= \dfrac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
A	0.231	500 K	0.14313	0.42534	0.5	0.28626	0.12176	0.52709	1000
3	0.224	500 K	0.14398	0.39367	0.5	0.28796	0.11336	0.50607	1000
4	0.229	500 K	0.14664	0.39122	0.5	0.29328	0.11474	0.50108	1000
5	0.222	500 K	0.14592	0.39052	0.5	0.29184	0.11397	0.51338	1000
6	0.221	500 K	0.14457	0.38409	0.5	0.28914	0.11104	0.50244	1000
A	0.230	500 K	0.14301	0.42526	0.5	0.28602	0.12163	0.52882	1000
3	0.219	500 K	0.14769	0.41203	0.5	0.29538	0.12170	0.55570	1000
4	0.231	500 K	0.14699	0.39195	0.5	0.29398	0.11523	0.49883	1000
5	0.228	500 K	0.14647	0.39136	0.5	0.29294	0.11464	0.50280	1000
6	0.225	500 K	0.14548	0.38859	0.5	0.29096	0.11303	0.50248	1000

Highest Efficiency = 0.55570

Average Efficiency = 0.51387

Lowest Efficiency = 0.49883

Table A5

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 5 MEGACYCLES

Element Number	RF Power Input Prf (Watts)	Light Cell Resistance (Ohms)	DC Calibration with L & N "K" Pot E_R (volts)	E_H (volts)	R_S (ohms)	$I_H = \dfrac{E_R}{R_S}$ (amps)	Heater Power (dc) $Pdc = E_H \times I_H$ (Watts)	RF system Efficiency $= \dfrac{Pdc}{Prf}$	RF Freq. (Mc)
1	1.54	500K	1.39632	0.38024	0.5	2.79264	1.06187	0.6895	5
3	1.63	500K	1.44192	0.38514	0.5	2.88384	1.11068	0.6814	5
4	1.59	500K	1.37102	0.41072	0.5	2.74204	1.12621	0.7083	5
8	1.45	500K	1.28854	0.39794	0.5	2.57708	1.02553	0.7072	5
1	1.54	500K	1.39651	0.37918	0.5	2.79302	1.05905	0.6876	5
4	1.55	500K	1.36494	0.39238	0.5	2.72988	1.07115	0.6910	5
8	1.45	500K	1.29371	0.39704	0.5	2.58742	1.02730	0.7084	5

Highest Efficiency = 0.7084
Average Efficiency = 0.6962
Lowest Efficiency = 0.6814

Table A-6

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 AT 30 Mc

Element Number	RF Power Input P_{rf} (watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot			$I_H = \dfrac{E_R}{R_S}$ (Amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $= \dfrac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
			E_R (Volts)	E_H (Volts)	R_S (Ohms)				
9	2.48	500 K	1.43208	0.36212	0.5	2.86416	1.03716	0.41816	30
8	2.05	500 K	1.22884	0.38386	0.5	2.45768	0.94340	0.46019	30
1	2.20	500 K	1.33466	0.36908	0.5	2.66932	0.98519	0.44781	30
10	2.19	500 K	1.32468	0.37984	0.5	2.64936	1.00633	0.45951	30
11	2.19	500 K	1.32099	0.38386	0.5	2.64198	1.01415	0.46308	30
9	2.47	500 K	1.43209	0.36222	0.5	2.86418	1.03746	0.42002	30
8	2.00	500 K	1.22792	0.37945	0.5	2.45584	0.93186	0.46593	30
1	2.27	500 K	1.34239	0.37066	0.5	2.68478	0.88514	0.43838	30
10	2.21	500 K	1.32596	0.38306	0.5	2.65192	1.01584	0.43965	30
11	2.20	500 K	1.31329	0.38535	0.5	2.62658	1.01215	0.45798	30

Highest Efficiency = 0.46595

Average Efficiency = 0.449071

Lowest Efficiency = 0.42002

Table A7

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 30 MEGACYCLES

Element Number	RF Power Input Prf (Watts)	Light Cell Resistance (Ohms)	DC Calibration with L & N "K" Pot E_R (volts)	E_H (volts)	R_S (ohms)	$I_H = \dfrac{E_R}{R_S}$ (amps)	Heater Power (dc) $Pdc = E_H \times I_H$ (Watts)	RF system Efficiency $= \dfrac{Pdc}{Prf}$	RF Freq. (Mc)
1	2.54	500K	1.35830	0.38121	0.5	2.7166	1.03559	0.40771	30
4	2.62	500K	1.35239	0.42303	0.5	2.7047	1.14416	0.43670	30
8	2.33	500K	1.27418	0.41029	0.5	2.5483	1.04554	0.44872	30
1	2.62	500K	1.38182	0.38424	0.5	2.7636	1.06188	0.40529	30
4	2.60	500K	1.34920	0.40837	0.5	2.6984	1.10195	0.42383	30
8	2.32	500K	1.27218	0.40854	0.5	2.5443	1.03945	0.44804	30
Low Loss Simulant	2.63	500K	1.37928	0.39253	0.5	2.7585	1.08279	0.41171	30
Low Loss Simulant	2.68	500K	1.37284	0.38913	0.5	2.7456	1.06842	0.39866	30

Highest Efficiency = 0.44872
Average Efficiency = 0.42258
Lowest Efficiency = 0.39866

F-E1805

Table A-8

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 250 Mc

MARK 2 Element Number	RF Input P_{rf} (watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot.			Heater Current $I = \dfrac{E_R}{R_S}$ (amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (watts)	RF System Efficiency $= \dfrac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
			E_R (volts)	E_H (volts)	R_S (ohms)				
2	2.63	500 K	1.4036	0.37739	0.5	2.8072	1.0594	0.4028	2.50
1	2.48	500 K	1.3634	0.38103	0.5	2.7268	1.0390	0.4189	2.50
3	2.75	500 K	1.4419	0.38055	0.5	2.8839	1.0974	0.3990	2.50
4	2.60	500 K	1.3693	0.38514	0.5	2.7386	1.0547	0.4056	2.50
8	2.32	500 K	1.2878	0.39081	0.5	2.5756	1.0065	0.4338	2.50
1	2.60	500 K	1.3971	0.37564	0.5	2.7943	1.0496	0.4037	2.50
2	2.51	500 K	1.3603	0.38143	0.5	2.7264	1.0377	0.4134	2.50
3	2.75	500 K	1.4432	0.38094	0.5	2.8863	1.0995	0.3998	2.50
4	2.55	500 K	1.3648	0.38796	0.5	2.7297	1.0590	0.4153	2.50
8	2.28	500 K	1.2900	0.39241	0.5	2.5800	1.0124	0.4440	2.50
Low-Loss Simulant	2.65	500 K	1.3872	0.38282	0.5	2.7745	1.0621	0.4010	2.50
Low-Loss Simulant	2.67	500 K	1.3836	0.38348	0.5	2.7672	1.0612	.3974	—

Highest Efficiency = .4189

Average Efficiency = .4112

Lowest Efficiency = .3974

A8

F-E1805

Table A-9

EFFICIENCY OF RF MATCHING SYSTEM AND FIRING MOUNT FOR MARK 2 MOD 0 IGNITION ELEMENT AT 1000 MEGACYCLES

Element Number	RF Power Input P_{rf} (watts)	Light Cell Resistance (ohms)	DC Calibration with L & N "K" Pot E_R (Volts)	E_H (Volts)	R_S (Ohms)	$I_H = \dfrac{E_R}{R_S}$ (Amps)	Heater Power (dc) $P_{dc} = E_H \times I_H$ (Watts)	RF System Efficiency $= \dfrac{P_{dc}}{P_{rf}}$	RF Freq. (Mc)
1	1.98	500 K	1.35256	0.38607	0.5	2.70512	1.04438	0.52746	1000
4	2.05	500 K	1.34124	0.40649	0.5	2.68248	1.09040	0.53190	1000
8	1.78	500 K	1.25446	1.25446	0.5	2.70832	1.070409	0.60135	1000
9	2.03	500 K	1.46547	0.37069	0.5	2.93094	1.06470	0.53206	1000
10	1.81	500 K	1.34136	0.39035	0.5	2.68272	1.047191	0.57856	1000
1	1.99	500 K	1.37284	0.39565	0.5	2.74568	1.086328	0.54589	1000
4	2.02	500 K	1.34936	0.43139	0.5	2.69872	1.164200	0.57633	1000
8	1.72	500 K	1.26784	0.40453	0.5	2.53568	1.025758	0.59637	1000
9	2.04	500 K	1.46316	0.37166	0.5	2.92632	1.087596	0.53312	1000
10	1.80	500 K	1.33982	0.38992	0.5	2.67964	1.044845	0.58046	1000

Highest Efficiency = 0.60135

Average Efficiency = 0.56036

Lowest Efficiency = 0.52746

APPENDIX B

BRUCETON DATA

B-1 BRUCETON TEST MK 1 MOD O SQUIB 5 MC

Functioning Levels (ζ) — Items 1–50

.0721	.0773	.0828	.0887	.0950	.102	.109	.117	.125	.134	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
				O						—	0.97	1
					X					0.9561	1.05	2
				O						—	1.00	3
					X					1.3051	0.98	4
				O						—		5
					X					1.6824	1.07	6
				O						—	1.11	7
					X					1.7058	1.20	8
				O						—	1.02	9
					X					0.9210	1.04	10
				O						—	0.89	11
					O					—	1.05	12
						X				0.3581	0.92	13
					X					0.6939	0.93	14
				O						—	1.07	15
				O						—	1.10	16
						X				0.8630	0.91	17
					X					0.5868	1.05	18
				X						1.6867	1.02	19
			O							—	0.95	20
				X						1.8088	—	21
			O							—	1.00	22
				O						—	0.82	23
					X					0.9376	0.96	24
				X						1.2630	0.95	25
			O							—	1.04	26
				X						2.7396	1.14	27
			O							—	1.06	28
				O						—	0.96	29
					X					0.6590	0.98	30
				O						—	1.04	31
					X					1.1086	1.08	32
				O						—	0.92	33
					X					0.8547	1.04	34
				X						1.2789	1.01	35
			X							1.4273	1.01	36
		X								2.2124	1.03	37
	O									—	1.08	38
	O									—	0.98	39
		O								—	1.00	40
			O							—	1.02	41
					X					0.7459	1.05	42
				O						—	1.04	43
					O					—	0.97	44
						X				0.9475	0.98	45
				O						—	1.00	46
						X				0.7641	0.84	47
					X					0.6914	0.97	48
				O						—	0.94	49
					X					0.5641	1.04	50
0	1	1	5	14	4					$n_1 =$	X	
1	1	5	12	4	0					$n_0 =$	O	

Functioning Levels (ζ) — Items 51–100

.0721	.0773	.0828	.0887	.0950	.102	.109	.117	.125	.134	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
				X						1.4508	1.10	51
			O							—	0.98	52
			O							—	1.03	53
				X						1.2299	1.04	54
				X						0.4939	0.86	55
			O							—	1.03	56
				O						—	0.99	57
					X					0.7450	1.01	58
				O						—	0.94	59
					X					0.9335	0.98	60
				X						0.3523	1.06	61
			O							—	1.00	62
				X						0.2586	0.89	63
			X							0.9780	0.95	64
		X								2.2787	0.97	65
O										—	0.98	66
	O									—	0.96	67
			O							—	1.07	68
				O						—	0.96	69
					X					0.8392	0.93	70
				O						—	0.98	71
					X					0.6616	0.92	72
				O						—	1.00	73
					X					1.9130	1.00	74
				X						0.8979	1.01	75
			O							—	1.01	76
				X						—	1.00	77
			O							—	0.98	78
				O						—	1.00	79
					O					—	1.06	80
						X				—	1.02	81
					X					0.9062	0.98	82
				O						—	1.05	83
					X					0.9181	0.84	84
				O						—	0.97	85
					X					1.1643	0.95	86
				X						0.7915	1.01	87
			O							—	0.92	88
			O							—	1.12	89
					O					—	1.03	90
						X				—	1.09	91
					X					0.6993	1.01	92
				O						—	1.06	93
					O					—	1.00	94
						X				1.0313	1.00	95
					X					1.1060	1.04	96
				O						—	1.05	97
					O					—	1.00	98
						X				0.8341	1.06	99
					X					1.0134	1.10	100
0	1	1	7	12	4					$n_1 =$	X	
1	1	7	12	4	0					$n_0 =$	O	

i	i²	n_o	n_x	$\zeta - Mw$
0	0	2	0	77.9
1	1	2	2	82.8
2	4	12	2	88.7
3	9	26	12	95.0
4	16	8	26	102.0
5	25	0	8	109.0
6	36			
Totals:		$N_o = 50$	$N_x = 50$	

Special Parameters

$c = (\log \zeta)_{i=0} = 1.89818$

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = .067 , .08$

Primary Statistics

$A = \Sigma i n$

$B = \Sigma i^2 n$

$M = (NB - A^2)/N^2$

$m = c + d (A/N \pm \frac{1}{2})^*$

$\sigma = 1.62 d (M + 0.029)\sqrt{\dfrac{N}{N-1}}$ **

*Use + for "o's;" - for "x's"

**Valid for M ≥ 0.3 only, otherwise consult 'Bruceton Report' (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Ms-1

	For "o's"	For "x's"
A =	136	186
B =	412	734
M =	.84160	.84160
m =	1.98478	1.98478
σ =	.04274	.04274

Secondary Statistics

$m = \dfrac{N_o m_o + N_x m_x}{N_o + N_x} = 1.98478$

$\sigma = \sqrt{\dfrac{N_o \sigma_o^2 + N_x \sigma_x^2}{N_o + N_x}} = .04274$

$\zeta = $ Antilog m = .096552 watts

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Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = .1		100-P% = 1	

$m = 1.98478$ $k_p^{(2)} = 3.090$ $m = 1.98478$ $k_p^{(2)} = 2.326$

$\sigma = .04274$ $k_x^{(2)} = 1.282$ $\sigma = .04274$ $k_x^{(2)} = 1.282$

$d = .03$ $G^{(3)} = .965$ $d = .03$ $G^{(3)} = .965$

$S = \frac{\sigma}{d} = 1.425$ $G^2 = .93122$ $S = \frac{\sigma}{d} = 1.425$ $G^2 = .93122$

$N = 100$ $H^{(3)} = 1.54$ $N = 100$ $H^{(3)} = 1.54$

$n^{(1)} = 50$ $H^2 = 2.3716$ $n^{(1)} = 50$ $H^2 = 2.3716$

(1) $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

(2) From BR*, p. 19, at given P or X

(3) From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= .03853$

Final Calculations

(99.9%) (90% Conf) = $m + k_p \sigma + Y$

$= 2.15537$ log units

$= .143099$ watts

(.1%) (90% Conf) = $m - k_p \sigma - Y$

$= 1.8149$ log units

$= .06519$ watts

---

(1) $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

(2) From BR*, p. 19, at given P or X

(3) From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= 0.029433$

Final Calculations

(99%) (90% Conf) = $m + k_p \sigma + Y$

$= 2.11362$ log units

$= 0.1299$ watt

(1%) (90% Conf) = $m - k_p \sigma - Y$

$= 1.8559$ log units

$= 0.07177$ watt

B2

B-2   BRUCETON TEST MK 1 MOD 0 SQUIB 30 KC

Functioning levels (ζ): .111, .119, .127, .136, .144, .152, .168, .180, .192, .206

Mark	Funct. Time (secs)	Resistance (Ω)	Item No.
X		1.03	1
O		1.00	2
X	0.3522	1.02	3
O	—	0.94	4
X	1.07312	0.98	5
O	—	0.96	6
X	0.3421	1.00	7
X	1.3734	0.97	8
X	1.9152	1.01	9
O	—	0.90	10
X	0.9912	1.02	11
O	—	0.99	12
X	1.0786	0.97	13
O	—	0.95	14
X	.8906	1.06	15
X	1.0486	1.01	16
O	—	1.06	17
O	—	0.90	18
X	1.2598	0.98	19
O	—	0.98	20
O	—	1.02	21
X	0.4957	1.03	22
X	1.1313	1.04	23
O	—	0.92	24
O	—	1.03	25
X	0.5286	0.97	26
X	0.8939	1.05	27
X	0.6331	0.95	28
O	—	0.97	29
O	—	1.03	30
O	—	1.08	31
X	0.8389	1.00	32
O	—	0.99	33
X	0.5546	1.00	34
O	—	0.99	35
O	—	0.94	36
X	0.5385	0.98	37
X	1.1909	1.05	38
O	—	1.04	39
X	1.3588	1.03	40
O	—	0.94	41
X	0.8192	0.97	42
O	—	0.99	43
O	—	0.94	44
X	0.5691	0.99	45
X	1.9441	0.94	46
X	0.8049	1.03	47
X	0.4557	0.99	48
O	—	0.97	49
X	1.3148	1.02	50
n_x = 0 4 8 9 6		X	
n_o = 3 2 8 5 0		O	

Mark	Funct. Time (secs)	Resistance (Ω)	Item No.
O	—	1.06	51
X		1.06	52
O	—	1.01	53
X	1.1132	0.98	54
O	—	1.07	55
O		1.02	56
X	1.2666	1.10	57
O	—	1.06	58
X	0.4144	0.98	59
O	—	1.01	60
X	1.1790	1.01	61
O	—	1.03	62
O	—	1.00	63
X	0.7731	1.05	64
O	—	1.01	65
O		0.95	66
X	0.7144	0.98	67
X	0.4012	1.10	68
O	—	0.98	69
O	—	0.95	70
X	0.7245	0.99	71
X	0.5129	0.98	72
X	1.5015	1.05	73
O	—	1.02	74
O	—	1.02	75
O	—	1.07	76
X	0.4001	1.02	77
X	0.6254	1.05	78
X	0.9908	0.97	79
O	—	1.00	80
O	—	0.98	81
O		1.02	82
X	0.4618	1.04	83
X	3.5891	0.99	84
O	—	0.95	85
X	0.8810	0.98	86
O	—	1.01	87
X	1.4432	0.99	88
O	—	0.92	89
O	—	0.98	90
X	0.5361	0.97	91
O	—	0.98	92
X	0.4935	0.97	93
O	—	0.96	94
X	0.6350	0.99	95
X	1.1168	0.97	96
O	—	0.93	97
X	1.1209	1.01	98
O	—	0.93	99
X	1.1099	0.97	100
n_x = 0 2 6 10 7		X	
n_o = 3 6 10 9 0		O	

i	i^2	n_o	n_x	$\zeta - MW$
0	0	6	0	111
1	1	13	6	119
2	4	18	13	127
3	9	12	19	136
4	16	0	13	146
5	25			
6	36			
Totals:	$N_o = 49$	$N_x = 51$		

Special Parameters

$c = (\log \zeta)_{i=o} = 2.04532$

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = .03$

Primary Statistics

$A = \Sigma\, i\, n$

$B = \Sigma\, i^2 n$

$M = (\, NB - A^2\,)/N^2$

$m = c + d\,(A/N \pm \frac{1}{2})$ *

$\sigma = 1.62\, d\, (M + 0.029)\sqrt{\dfrac{N}{N-1}}$ **

*"Use + for "o's;" - for "x's"

**Valid for M ≥ 0.3 only, otherwise consult "Bruceton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Ma-1

	For "o's"	For "x's"
A =	85	141
B =	193	437
M =	.92961	.92503
m =	2.11236	2.08236
σ =	.04512	.09805

Secondary Statistics

$m = \dfrac{N_o m_o + N_x m_x}{N_o + N_x} = 2.09706$

$\sigma = \sqrt{\dfrac{N_o\,\sigma_o^2 + N_x\,\sigma_x^2}{N_o + N_x}} = .046637$

$\zeta = \text{Antilog } m = .12604 \ \text{WATTS}$

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Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = 0.1		100-P% = 1	

m = 2.09706	k_p ② = 3.09	m = 2.09706	k_p ② = 2.326
σ = 0.046637	k_x ② = 1.282	σ = 0.046637	k_x ② = 1.282
d = 0.03	G ③ = 0.957	d = 0.03	G ③ = 0.957
$S = \frac{\sigma}{d} = 1.56$	$G^2 = 0.91589$	$S = \frac{\sigma}{d} = 1.56$	$G^2 = 0.91589$
N = 100	H ③ = 1.59	N = 100	H ③ = 1.59
n ① = 50	$H^2 = 2.5281$	n ① = 50	$H^2 = 2.528$

① $n = \frac{N}{2}$ when N is even integer

   $n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1 \cdot 2}{n}\right)\left(\frac{G^2 + H^2 k_p^{\,2}}{n}\right)^{1/2}\sigma$$

$= 0.043334$

Final Calculations

(99.9%) (90% Conf) = $m + k_p\sigma + Y$

$= 2.28450$ log units

$= 0.192530$ watt

(0.1%) (90% Conf) = $m - k_p\sigma - Y$

$= 1.90961$ log units

$= 0.08121$ watt

① $n = \frac{N}{2}$ when N is even integer

   $n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1 \cdot 2}{n}\right)\left(\frac{G^2 + H^2 k_p^{\,2}}{n}\right)^{1/2}\sigma$$

$= 0.0330729$

Final Calculations

(99%) (90% Conf) = $m + k_p\sigma + Y$

$= 2.23855$ log units

$= 0.1732$ watt

(1%) (90% Conf) = $m - k_p\sigma - Y$

$= 1.95551$ log units

$= 0.090262$ watt

B4

B-3 BRUCETON TEST MK 1 MOD 0 SQUIB 250 MC

Functioning Levels (ζ): .0779, .0834, .0894, .0968, .103, .110, .118, .126, .135, .146

Result	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
X	1.5890	1.00	1
O	–	1.10	2
X	0.6942	0.97	3
O	–	1.03	4
O	–	1.07	5
O	–	0.97	6
X	0.6756	1.01	7
X	1.0075	1.04	8
O	–	0.80	9
O	–	1.10	10
X	0.8848	0.98	11
O	–	0.99	12
X	0.6827	1.08	13
X	0.7604	1.02	14
O	–	0.99	15
X	1.0091	0.97	16
O	–	0.88	17
O	–	0.96	18
X	0.4527	0.99	19
X	0.7664	1.04	20
X	0.9126	0.95	21
O	–	1.01	22
X	1.9434	0.99	23
O	–	1.05	24
O	–	0.87	25
O	–	0.97	26
X	0.7472	1.00	27
X	1.0044	1.02	28
O	–	0.97	29
O	–	0.95	30
X	0.8157	1.01	31
O	–	1.01	32
O	–	1.04	33
X	0.4278	1.01	34
O	–	0.95	35
	0.7890	1.04	36
X	0.7781	0.99	37
X	0.4410	1.04	38
O	–	0.99	39
X	1.1160	0.99	40
O	–	1.02	41
O	–	0.98	42
X	0.8316	0.95	43
X	1.5072	0.98	44
O	–	0.96	45
O	–	0.95	46
O	–	1.00	47
X	0.4991	0.86	48
X	0.8262	0.99	49
O	–	0.98	50

n1 = 0 4 8 9 3 → n1 = 24 (X)
n0 = 4 9 10 3 0 → n0 = 26 (O)

Functioning Levels (ζ): .0779, .0834, .0894, .0968, .103, .110, .118, .126, .135, .146

Result	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
O	–	1.07	51
X	0.5314	1.01	52
O	–	0.97	53
X	0.5625	–	54
X	0.6706	0.92	55
O	–	1.00	56
O	–	0.94	57
X	0.3096	1.00	58
O	–	1.05	59
X	0.5770	0.98	60
X	0.7811	0.90	61
X	0.5424	1.08	62
X	1.3132	1.02	63
O	–	1.00	64
O	–	0.96	65
X	1.0314	1.01	66
O	–	1.04	67
X	0.4399	0.94	68
O	–	1.06	69
O	–	1.00	70
X	1.5477	0.98	71
O	–	0.97	72
X	0.8094	0.85	73
O	–	1.10	74
O	–	0.97	75
X	0.3284	0.96	76
X	0.5574	0.92	77
X	1.0692	0.92	78
O	–	1.02	79
O	–	1.00	80
X	1.0848	1.05	81
X	1.0992	0.98	82
X	1.9439	0.92	83
O	–	0.98	84
O	–	1.03	85
X	0.7070	0.97	86
X	0.9554	0.82	87
O	–	1.01	88
X	1.3684	1.05	89
O	–	1.02	90
O	–	0.98	91
X	1.2042	0.98	92
X	1.2310	0.93	93
O	–	0.96	94
X	2.6586	1.06	95
O	–	0.92	96
O	–	0.98	97
O	–	0.93	98
X	0.6842	0.98	99
X	0.9399	0.99	100

n1 = 0 6 8 7 5 → n1 = 26 (X)
n0 = 6 7 6 5 0 → n0 = 27 (O)

B5

i	i²	n₀	n₂	ζ -$\eta\omega$
0	0	10	0	103
1	1	16	10	110
2	4	16	16	118
3	9	8	16	126
4	16	0	8	135
5	25			
6	36			
Totals:		$N_0 = 50$	$N_1 = 50$	

Special Parameters

$c = (\log \zeta)_{i=0} = $ *2.01284*

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = $ *.03*

Primary Statistics

$A = \Sigma$ i n

$B = \Sigma$ i² n

$M = (NB-A^2)/N^2$

$m = c + d (A/N \pm \frac{1}{2})^*$

$\sigma = 1.62 d (M + 0.029)\sqrt{\frac{N}{N-1}}$ **

*Use + for "o's;" - for "x's"

**Valid for M ≥ 0.3 only, otherwise consult "Bruceton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Ms-1

	For "o's"	For "x's"
A =	72	128
B =	158	346
M =	.96640	.96640
m =	2.05104	2.05104
σ =	.048875	.048875

Secondary Statistics

$m = \frac{N_0 m_0 + N_1 m_1}{N_0 + N_1} = $ *2.05104*

$\sigma = \sqrt{\frac{N_0 \sigma_0^2 + N_1 \sigma_1^2}{N_0 + N_1}} = $ *.048875*

ζ = Antilog m = *112.49 WATTS*

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Probability Levels	**Confidence Level**	**Probability Levels**	**Confidence Level**
P% = *99.9*	X = *90*	P% = *99*	X = *90*
100-P% = *.1*		100-P% = *.1*	
m = *2.05104*	k_p ② = *3.090*	m = *2.05104*	k_p ② = *2.326*
σ = *.048875*	k_x ② = *1.282*	σ = *.048875*	k_x ② = *1.282*
d = *.03*	G ③ = *.954*	d = *.03*	G ③ = *.954*
$S = \frac{d}{\sigma} = $ *.62916*	G² = *.9011*	$S = \frac{d}{\sigma} = $ *.62916*	G² = *.9011*
N = *100*	H ③ = *1.617*	N = *100*	H ③ = *1.617*
n ① = *50*	H² = *2.6146*	n ① = *50*	H² = *2.6146*

① $n = \frac{N}{2}$ when N is **even** integer	① $n = \frac{N}{2}$ when N is **even** integer
$n = \frac{N+1}{2}$ when N is **odd** integer	$n = \frac{N+1}{2}$ when N is **odd** integer
② From BR*, p. 19, at given P or X	② From BR*, p. 19, at given P or X
③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5	③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)	**Confidence Interval (Y)**
$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$	$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$
= *0.046144*	= *0.03519255*

Final Calculations	**Final Calculations**
(*99%*) (*90%* Conf) = m+k_p σ + Y	(*99%*) (*90%* Conf) = m+k_p σ + Y
= *2.24820* log units	= *2.18991* log units
= *0.17709* WATT	= *0.15845* WATTS
(*.1%*) (*90%* Conf) = m-k_p σ - Y	(*1%*) (*90%* Conf) = m-k_p σ - Y
= *1.85388* log units	= *1.90217* log units
= *0.071426*	= *0.07983* WATTS

B6

BRUCETON TEST MK 1 MOD 0 SQUIB 1000 Mc

.152	.163	.174	.187	.200	.214	.230	.246	.263	Funct. Time (secs)	Ω	Item No.
			X						2.61376	0.98	1
		O							–	0.92	2
			X						1.33786	0.94	3
		O							–	0.97	4
			X						1.19542	0.92	5
		O							–	1.00	6
		O							–	0.96	7
				X					.92022	0.92	8
			O						–	0.92	9
				X					.78576	0.92	10
			X						1.02220	1.02	11
		X							1.25096	0.90	12
	O								–	1.05	13
		X							1.01453	.95	14
	O								–	.96	15
		O							–	0.94	16
			O						–	1.00	17
				X					0.45235	0.95	18
		X							0.99686	0.92	19
			O						–	0.90	20
				O					–	0.89	21
					O				–	0.90	22
					X				0.51894	1.04	23
				X					0.76499	0.95	24
			O						–	1.00	25
				X					.46380	0.94	26
		X							1.19620	0.95	27
			O						–	0.95	28
		X							1.08956	0.94	29
			X						0.96433	1.01	30
	@								–	0.95	31
		X							0.97222	0.95	32
X									–	0.96	33
O									–	1.00	34
		O							–	0.97	35
			X						1.29637	0.97	36
	O								–	0.93	37
		O							–	0.96	38
				X					1.10385	0.97	39
			O						–	0.96	40
			O						–	0.96	41
				X					1.56338	1.01	42
			O						–	0.96	43
				X					–	0.95	44
			X						2.24720	0.96	45
		X							1.30083	0.98	46
	O								–	0.76	47
		O							–	1.07	48
		O							–	0.95	49
				X					1.06542	0.95	50
	0	16	9	8	1				$n_x = 25$		X
1	6	9	8	1	0				$n_0 = 25$		O

0.152	.163	.174	.187	.200	.214	.230	.246	.263	Funct. Time (secs)	Ω	Item No.
					O				–	0.95	51
						O			–	0.93	52
							X		0.58383	1.00	53
						X			0.62154	0.95	54
					X				1.02805	1.00	55
				O					–	1.01	56
					O				–	0.98	57
						X			1.13684	0.98	58
					O				–	0.97	59
						X			0.61744	0.98	60
					O				–	0.95	61
						O			–	0.91	62
							X		0.85747	0.90	63
						X			0.97428	0.91	64
					O				–	1.04	65
					O				–	0.92	66
							X		0.85274	0.95	67
						X			0.78870	0.97	68
					O				–	0.92	69
						X			0.62307	0.93	70
					X				0.96742	0.91	71
				O					–	0.91	72
					O				1.42388	1.01	73
						X			0.58359	1.00	74
					X				1.00075	0.95	75
				O					–	1.01	76
				O					–	1.00	77
					O				–	0.98	78
							X		0.56778	0.89	79
					O				–	0.92	80
							X		0.61289	0.95	81
					O				–	1.01	82
							X		0.78368	1.00	83
					X				1.46647	0.96	84
					X				0.91489	0.92	85
				O					–	0.98	86
				O					–	0.99	87
					X				0.66573	0.99	88
				O					–	0.98	89
					X				1.41505	1.03	90
			O						–	0.95	91
					X				0.45479	0.96	92
				X					0.89510	1.01	93
			O						–	0.94	94
			X						0.71009	0.90	95
			O						–	0.91	96
			O						–	0.90	97
					X				0.38367	0.96	98
			X						2.16910	0.98	99
			O						–	0.99	100
			0	7	12	6			$n_x = 25$		X
			7	12	6	0			$n_0 = 25$		O

i	i²	n₀	nₓ	ζ = MW
0	0	1	0	163
1	1	6	1	174
2	4	16	6	187
3	9	20	16	200
4	16	7	20	214
5	25	0	7	230
6	36			
Totals:		N₀ =	Nₓ =	

Special Parameters

$c = (\log \zeta)_{i=0} = $ _2.21219_

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = $ _.03_

Primary Statistics

$A = \Sigma\, i\, n$

$B = \Sigma\, i^2\, n$

$N = (NB - A^2)/N^2$

$m = c + d\,(A/N \pm \frac{1}{2})$

$\sigma = 1.62\, d\,(N + 0.029)\sqrt{\frac{N}{N-1}}$ **

* Use + for "o's" - for "x's"

** Valid for N > 0.3 only, otherwise consult "Bruceton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. 14-1

	For "o's"	For "x's"
A =	126	176
B =	362	664
N =	.85960	.85960
m =	2.30279	2.30279
σ =	.04510	.04510

Secondary Statistics

$m = \frac{N_0 m_0 + N_x m_x}{N_0 + N_x} = $ _2.30279_

$\sigma = \sqrt{\frac{N_0 \sigma_0^2 + N_x \sigma_x^2}{N_0 + N_x}} = $ _.04510_

ζ = Antilog m = _.20061_ watts

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Probability Levels	Confidence Level
P% = _99.9_	X% = _90_
100-P% = _1_	

m = _2.30279_	k_p ② = _3.090_
σ = _.04464_	k_x ② = _1.282_
d = _.03_	σ ③ = _.961_
$S = \frac{\sigma}{d}$ = _1.488_	σ² = _.9235_
N = _100_	H ③ = _1.56_
n ① = _50_	H² = _2.434_

① $n = \frac{N}{2}$ when N is even integer

  $n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_x^2}{n}\right)^{1/2}\sigma$$

= _.04078436_

Final Calculations

(99.9%) (90% Conf) = $m + k_p\sigma + Y$

  = _2.48857_ log units

  = _.30802_ watts

(99.9%) (90% Conf) = $m - k_p\sigma - Y$

  = _2.11701_ log units

  = _.1398_ watts

Probability Levels	Confidence Level
P% = _99_	X% = _90_
100-P% = _1_	

m = _2.30279_	k_p ② = _2.326_
σ = _0.04464_	k_x ② = _1.282_
d = _0.03_	σ ③ = _0.961_
$S = \frac{\sigma}{d}$ = _1.488_	σ² = _0.9235_
N = _100_	H ③ = _1.56_
n ① = _50_	H² = _2.434_

① $n = \frac{N}{2}$ when N is even integer

  $n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_x^2}{n}\right)^{1/2}\sigma$$

= _0.03111061_

Final Calculations

(99%) (90% Conf) = $m + k_p\sigma + Y$

  = _2.43773_ log units

  = _.2239_ milliwatts

(1%) (90% Conf) = $m - k_p\sigma - Y$

  = _2.16265_ log units

  = _147.18_ milliwatts

B-4 BRUCETON TEST MK 2 MOD 0 ELEMENT 5 MC

Functioning Levels (ζ)							FUNCT. TIME secs	RESISTANCE Ω	ITEM NO.	Functioning Levels (ζ)							FUNCT. TIME secs	RESISTANCE Ω	ITEM NO.
		1.03	1.10	1.18	1.26	1.35						1.03	1.10	1.18	1.26	1.35			
				O			–	.105	1						X	.228372	.112	51
					O		–	.110	2					X		.686500	.096	52
						X	.12222	.105	3				O			–	.012	53
				X			★	.101	4					O		–	.107	54
				O			–	.110	5						X	.218163	.081	55
				X			★	.100	6					X		.418044	.100	56
				O			–	.103	7				O			–	.091	57
				X			★	.113	8					O		–	.101	58
				O			–	.104	9						X	.173209	.108	59
				X			★	.106	10					X		.461746	.125	60
				O			–	.106	11				O			–	.091	61
				X			–	.112	12					O		–	.108	62
			X				★	.105	13						X	.090076	.098	63
		O					–	.102	14						X	.978690	.100	64
			X				★	.103	15				O			–	.058	65
		O					–	.107	16						X	.225764	.095	66
			O				–	.102	17				O			–	.112	67
			X				★	.100	18					O		–	.105	68
			O				–	.108	19						X	.061874	.097	69
			X				★	.106	20					X		.668470	.092	70
			O				–	.105	21				O			–	.098	71
			X				★	.098	22				O			–	.110	72
			O				–	.105	23						X	.456757	.111	73
			X				★	.102	24				O			–	.112	74
			O				–	.100	25						X	.077086	.104	75
			X				.17832	.095	26					X		.371377	.105	76
		X					★	.104	27			X				.95-214	.107	77
	O						–	.108	28		O					–	.107	78
	O						–	.100	29		O					–	1.01	79
			X				★	.110	30			O				–	.115	80
	O						–	.101	31						X	.115092	.100	81
		X					★	.095	32					X		.372218	.105	82
	X						.951730	.106	33			O				–	.100	83
	O						–	.095	34					X		.462057	.094	84
	O						–	.100	35					X		.645810	.106	85
		X					.339	.105	36		O					–	.058	86
	O						–	.100	37		O					–	.103	87
		X					.009705	.090	38				X			.562359	.094	88
	X						.667347	.102	39		O					–	.095	89
O							–	.110	40		O					.203946	.107	90
	X						.442181	.100	41		O					–	.110	91
	O						–	.095	42				X			.402804	.102	92
	O						–	.096	43		O					–	.110	93
		O					–	.097	44			X				.288443	.094	94
			X				★	.095	45		O					–	.095	95
		X					★	.095	46		O					–	.115	96
	O						–	.108	47				X			.115653	.102	97
		X					.17326N	.100	48			X				.053918	.119	98
	O						–	.096	49		O					–	.107	99
		O					–	.095	50		O					–	.100	100
		O	6	16	2		n_x = 24		X		O	2	14	9		n_x = 25		X
		6	17	3	O		n_o = 26		O		2	14	9	O		n_o = 25		O

B9

i	i^2	n_o	n_x	ζ in Amps
0	0	8	0	1.10
1	1	31	8	1.18
2	4	12	30	1.26
3	9	0	11	1.35
4	16			
5	25			
6	36			
Totals:		$N_o = 51$	$N_x = 49$	

Special Parameters

$c = (\log \zeta)_{i=0} = 0.04139$

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = .03$

Primary Statistics

$A = \Sigma\, i\, n$

$B = \Sigma\, i^2 n$

$M = (NB - A^2)/N^2$

$m = c + d\,(A/N \pm \tfrac{1}{2})^*$

$\sigma = 1.62\, d\,(M + 0.029)\sqrt{\dfrac{N}{N-1}}$ **

*Use + for "o's;" − for "x's"

**Valid for M ≥ 0.3 only, otherwise consult 'Bruceton Report' (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Mm-1

	For "o's"	For "x's"
A =	55	101
B =	79	227
M =	0.38600	0.38401
m =	0.08874	0.08823
σ =	0.02037	0.02028

Secondary Statistics

$m = \dfrac{N_o\, m_o + N_x\, m_x}{N_o + N_x} = 0.08849$

$\sigma = \sqrt{\dfrac{N_o\, \sigma_o^2 + N_x\, \sigma_x^2}{N_o + N_x}} = 0.02033$

$\zeta = \text{Antilog } m = 1.226 \text{ WATTS}$

DATE 8-21-61   INITIALS   PAGE

Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100−P% = 0.1		100−P% = 1	

m = 0.08849	$k_p^{(2)} = 3.09$	m = 0.08849	$k_p^{(2)} = 2.326$
σ = 0.02033	$k_x^{(3)} = 1.282$	σ = 0.02033	$k_x^{(2)} = 1.282$
d = 0.03	$G^{(3)} = 1.066$	d = 0.03	$G^{(3)} = 1.066$
$S = \dfrac{\sigma}{d} = 0.677$	$G^2 = 1.136356$	$S = \dfrac{\sigma}{d} = 0.677$	$G^2 = 1.1363$
N = 100	$H^{(3)} = 1.26$	N = 100	$H^{(3)} = 1.26$
$n^{(1)} = 50$	$H^2 = 1.5876$	$n^{(1)} = 50$	$H^2 = 1.5876$

(1) $n = \dfrac{N}{2}$ when N is **even** integer

$n = \dfrac{N+1}{2}$ when N is **odd** integer

(2) From BR*, p. 19, at given P or X

(3) From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\dfrac{n+1.2}{n}\right)\left(\dfrac{G^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= 0.0152337$

Final Calculations

(99%) (90% Conf) = m + $k_p\sigma$ + Y

$= 0.16654$ log units

$= 1.4673$ Watts

(0.1%) (90% Conf) = m − $k_p\sigma$ − Y

$= 0.01045$ log units

$= 1.0243$ Watts

---

(1) $n = \dfrac{N}{2}$ when N is **even** integer

$n = \dfrac{N+1}{2}$ when N is **odd** integer

(2) From BR*, p. 19, at given P or X

(3) From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\dfrac{n+1.2}{n}\right)\left(\dfrac{G^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= 0.0117046$

Final Calculations

(99%) (90% Conf) = m + $k_p\sigma$ + Y

$= 0.14755$ log units

$= 1.4045$ Watt

(1%) (90% Conf) = m − $k_p\sigma$ − Y

$= 0.02943$ log units

$= 1.0701$ Watt

BRUCETON TEST MK 2 MOD 0 IGNITION ELEMENT
30 Mc (Repeat Test)   F-B1805

1.56	1.67	1.79	1.91	2.05	2.20	2.35	2.52	2.70	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
				X					---	.100	1
			O						---	.095	2
				X					0.48453	.100	3
			X						Missed t.	.095	4
	O								---	.100	5
		X							missed	.101	6
	X								1.78812	.105	7
O									---	.095	8
	O								---	.106	9
		O							---	.092	10
				X					.343231	.105	11
			X						.453110	.099	12
	O								---	.090	13
		O							---	.096	14
				X					.224473	.110	15
		O							---	.100	16
				X					.169449	.105	17
		O							---	.104	18
				X					.446556	.098	19
		O							---	.101	20
				X					.379210	.100	21
		O								.100	22
				X					1.184453	.105	23
		O							---	.095	24
				X					.408014	.107	25
		O							---	.105	26
				X					.439036	.105	27
		O							---	.106	28
				X					.165355	.090	29
			X						.564075	.105	30
	O								---	.090	31
		O							---	.100	32
				X					.191785	.100	33
			X						.558972	.094	34
		X							.26328	.104	35
O									---	.094	36
	O								---	.090	37
		O							---	.089	38
			O						---	.090	39
					X				.128199	.102	40
			X						.276661	.095	41
		X							.723825	.090	42
	O								---	.100	43
		O							---	.090	44
			X						.244478	.097	45
	O								---	.090	46
	X								.928037	.095	47
O									---	.100	48
	O								---	.096	49
		O							---	.096	50
0	3	6	14	1					n₁ = 24		X
3	7	15	1	0					n₀ = 26		O

1.56	1.67	1.79	1.91	2.05	2.20	2.35	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
			X				.151334	.105	51
			O				-	.100	52
			X				.225657	.102	53
			O				-	.101	54
				O			-	.102	55
					X		.097223	.100	56
			X				.219763	.101	57
			O				-	.098	58
			X				.728974	.094	59
			O				-	.098	60
			X				.352954	.105	61
		X					.637321	.102	62
	O						-	.094	63
		X					missed	.105	64
O							-	.095	65
	O						-	.106	66
			X				.494908	.105	67
		O					-	.095	68
			X				.358085	.100	69
		X					missed	.107	70
O							-	.110	71
	O						-	.103	72
			X				.323172	.110	73
		O					-	.105	74
			X				.138832	.105	75
		O					-	.097	76
			X				.425668	.099	77
		X					.758932	.108	78
O							-	.106	79
	O						-	.095	80
			X				.607774	.102	81
		O					-	.106	82
			X				.736332	.106	83
		X					.772614	.100	84
	X						1.017622	.107	85
O							-	.098	86
O							-	.102	87
		O					-	.105	88
			O				-	.100	89
					X		1.134676	.092	90
			X				.507455	.100	91
		X					1.333180	.106	92
	O						-	.099	93
		O					-	.095	94
			X				.673662	.090	95
	X						.938012	.103	96
O							-	.099	97
	O						-	.105	98
		O					-	.094	99
				X			.182215	.104	100
0	1	7	14	3			n₁ = 25		X
1	7	14	3	0			n₀ = 25		O

B11

i	i^2	n_o	n_x	ζ = watts
0	0	4	0	1.67
1	1	14	4	1.79
2	4	29	13	1.91
3	9	4	28	2.05
4	16	0	4	2.20
5	25			
6	36			
Totals:	N_o=51	N_x=49		

Special Parameters

$c = (\log \zeta)_{i=o} = $ .22272

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = $ 0.3

Primary Statistics

$A = \Sigma \, i \, n$

$B = \Sigma \, i^2 \, n$

$M = (NB - A^2)/N^2$

$m = c + d \, (A/N \pm \frac{1}{2})^*$

$\sigma = 1.62 \, d \, (M + 0.029)^{**}\sqrt{\frac{N}{N-1}}$ ∞

*Use + for "o's", − for "x's"

**Valid for M > 0.3 only, otherwise consult "Bruceton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Mm-1

	For "o's"	For "x's"
A =	84	130
B =	166	372
M =	.542099	.55310
m =	.28684	.28732
σ =	.02791	.02858

Secondary Statistics

$m = \frac{N_o m_o + N_x m_x}{N_o + N_x} = $ .28708

$\sigma = \sqrt{\frac{N_o \sigma_o^2 + N_x \sigma_x^2}{N_o + N_x}} = $ .02824

$\zeta = $ Antilog $m = $ 1.9368 watts

| DATE 2-1-62 | INITIALS | |

Probability Levels	Confidence Level
P% = 99.9	X% = 90
100−P% = 0.1	
m = .28708	$k_p^{\textcircled{2}} = $ 3.090
σ = .02824	$k_x^{\textcircled{2}} = $ 1.282
d = .03	$G^{\textcircled{3}} = $ 1.012
$S = \frac{\sigma}{d} = $ 0.9413	$G^2 = $ 1.024144
N = 100	$H^{\textcircled{3}} = $ 1.36
$n^{\textcircled{1}} = $ 50	$H^2 = $ 1.8496

$\textcircled{1}$ $n = \frac{N}{2}$ when N is **even** integer

$n = \frac{N+1}{2}$ when N is **odd** integer

$\textcircled{2}$ From BR*, p. 19, at given P or X

$\textcircled{3}$ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{G^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= $ .02266

Final Calculations

(99.9%) (90 % Conf) = $m + k_p \sigma + Y$

$= $ .39700 log units

$= $ 2.4946 watts

(0.1%) (90 % Conf) = $m − k_p \sigma − Y$

$= $ .17716 log units

$= $ 1.5037 watts

Probability Levels	Confidence Level
P% = 99	X% = 90
100−P% = 1	
m = 0.28708	$k_p^{\textcircled{2}} = $ 2.326
σ = 0.02824	$k_x^{\textcircled{2}} = $ 1.282
d = 0.03	$G^{\textcircled{3}} = $ 1.012
$S = \frac{\sigma}{d} = $ 0.9413	$G^2 = $ 1.024144
N = 100	$H^{\textcircled{3}} = $ 1.36
$n^{\textcircled{1}} = $ 50	$H^2 = $ 1.8496

$\textcircled{1}$ $n = \frac{N}{2}$ when N is **even** integer

$n = \frac{N+1}{2}$ when N is **odd** integer

$\textcircled{2}$ From BR*, p. 19, at given P or X

$\textcircled{3}$ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{G^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= $ 0.01741298

Final Calculations

(99%) (90% Conf) = $m + k_p \sigma + Y$

$= $ 0.370179 log units

$= $ 2.3452 watts

(1%) (90% Conf) = $m − k_p \sigma − Y$

$= $ 0.20398 log units

$= $ 1.5995 watts

Bruceton Firing Data For MARK 2 MOD 0 Ignition Element - 250 Mc

Functioning Levels (ζ)									FUNCT. TIME secs	RESISTANCE Ω	ITEM NO.
1.46	1.63	1.83	2.05	2.30	2.68	2.90	3.25	3.65			
					X				.368682	.103	1
			X						.743897	.101	2
		O							—	.096	3
			X						.064128	.100	4
		O							—	.093	5
			X							.106	6
		O								.104	7
			O							.100	8
			O							.106	9
				X						.095	10
			X						.205773	.106	11
		X							.967059	.107	12
	O									.112	13
		O								.105	14
			X						.242663	.097	15
		O								.106	16
			O							.122	17
			O							.098	18
					X				.091563	.096	19
			X						.132897	.104	20
		O								.130	21
			X							.120	22
		X							.229790	.105	23
		O								.102	24
		X							.204996	.110	25
		O								.098	26
		O								.106	27
			X						.061479	.104	28
		X								.106	29
		O								.112	30
			X						.131968	.106	31
		X							.470395	.105	32
	O								—	.112	33
	O									.101	34
		X							.152173	.106	35
		O								.102	36
		X							.534580	.101	37
	X								.532379	.101	38
	O								—	.102	39
		O							—	.112	40
		X							.130611	.110	41
		O							—	.107	42
		X							.162261	.108	43
		O							—	.106	44
		X							.840741	.111	45
		O							—	.097	46
		X							.207427	.110	47
		O								.096	48
		X								.112	49
		O								.116	50
			O 6 14 4 1						$n_1 = 25$		X
			6 14 4 1 0						$n_0 = 25$		O

Functioning Levels (ζ)									FUNCT. TIME secs	RESISTANCE Ω	ITEM NO.
1.45	1.63	1.83	2.05	2.30	2.58	2.90	3.25	3.65			
				O						.109	51
					X					.110	52
				X					.142076	.104	53
			O						—	.105	54
				O					—	.105	55
					X				—	.106	56
				X					.410851		57
			X						.345174	.100	58
		O							—	.107	59
			X						.782327	.101	60
		O								.102	61
			X						.615285	.106	62
		O								.099	63
			O							.112	64
				X					—	.101	65
			O							.105	66
			O							.105	67
				X					.106 936	.110	68
			O							.096	69
				X						.109	70
			X							.100	71
		O								.109	72
		O								.095	73
				X					.384224	.105	74
				X					.184359	.102	75
		X							.316762	.106	76
	O								—	.109	77
		X							.339639	.105	78
	O									.106	79
		O								.102	80
			X							.100	81
		O								—	.105	82
			X						.91283	.115	83
			X						.721724	.103	84
	O									.105	85
		O									.100	86
			X						.089887	.102	87
	X								.174982	.108	88
	O								—	.096	89
		O								.106	90
			X						.407131	.096	91
		O							—	.103	92
			X						.292228	.100	93
		O							—	.103	94
			X						.198401	.112	95
		O							—	.103	96
			X						.316694	.100	97
	O									.112	98
		X							.123740	.098	99
		O								.104	100
	O 1 3 17 9 1								$n_1 = 50$		X
	1 3 17 9 10								$n_0 = 50$		O

i	i^2	n_o	n_x	ζ =WATT
0	0	13	0	1.83
1	1	27	13	2.05
2	4	9	27	2.30
3	9	1	9	2.58
4	16	0	1	2.90
5	25			
6	36			
Totals:		N_o = 50	N_x = 50	

Special Parameters

$c = (\log \zeta)_{i_m} = 0.26245$

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = .05$

Primary Statistics

$A = \Sigma i n$

$B = \Sigma i^2 n$

$M = (NB - A^2)/N^2$

$m = c + d (A/N \pm \frac{1}{2})^\circ$

$\sigma = 1.62 d (M + 0.029)\sqrt{\dfrac{N}{N-1}}$ **

° Use + for "o's;" - for "x's"

** Valid for M ⩾ 0.3 only, otherwise consult "Bruceton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Sa-1

	For "o's"	For "x's"
A =	48	
B =	72	
M =	0.51840	
m =	0.33545	
σ =	.044790	

Secondary Statistics

$m = \dfrac{N_o m_o + N_x m_x}{N_o + N_x} =$ _____

$\sigma = \sqrt{\dfrac{N_o \sigma_o^2 + N_x \sigma_x^2}{N_o + N_x}} =$ _____

ζ = Antilog m = 2.165 WATTS

DATE 8/11/61	INITIALS JPL	PAGE

Probability Levels	Confidence Level
P% = 99.9	X% = 90
100-P% = 0.1	

m = 0.33545	$k_p^{②}$ = 3.09
σ = 0.044790	$k_x^{②}$ = 1.282
d = 0.05	$G^{③}$ = 1.020
$S = \frac{\sigma}{d}$ = 0.896	G^2 = 1.0404
N = 100	$H^{③}$ = 1.34
$n^{①}$ = 50	H^2 = 1.7956

① $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ⩾ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= 0.0354598$

Final Calculations

(99.9%) (0.1% Conf) = $m + k_p \sigma + Y$

$= 0.50931$ log units

$= 3.2308$ Watt

(0.1%) (90% Conf) = $m - k_p \sigma - Y$

$= 0.16159$ log units

$= 1.4507$

Probability Levels	Confidence Level
P% = 99	X% = 90
100-P% = 1	

m = 0.33545	$k_p^{②}$ = 2.326
σ = 0.044790	$k_x^{②}$ = 1.282
d = 0.05	$G^{③}$ = 1.020
$S = \frac{\sigma}{d}$ = 0.896	G^2 = 1.0404
N = 100	$H^{③}$ = 1.34
$n^{①}$ = 50	H^2 = 1.7956

① $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ⩾ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right)\left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2}\sigma$$

$= 0.02727033$

Final Calculations

(99%) (90% Conf) = $m + k_p \sigma + Y$

$= 0.46690$ log units

$= 2.9302$ Watt

(1%) 90% Conf) = $m - k_p \sigma - Y$

$= 0.20409$ log units

$= 1.5995$

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BRUCETON TEST MK 2 MOD 0 IGNITION ELEMENT 1000 Mc   F-B1805

Functioning Levels (ζ)					FUNCT. TIME secs	RESISTANCE Ω	ITEM NO.
1.19	1.27	1.39	1.49	1.60			
			X		0.35999		1
	0				–		2
		X			0.26222		3
	0				0.57752		4
0					–		5
	0				–		6
			X		0.20892		7
	0				–		8
		X			0.04599		9
	0				–		10
		X			0.07166		11
	0				–		12
		X			0.30865		13
	X				0.49039		14
X					1.4784		15
0					–		16
	0				–		17
		0			–		18
			X		0.36572		19
		0			–		20
			0		–		21
				X	0.05109		22
		X			0.11151		23
	0				–		24
			X		0.30358		25
	0				–		26
		X			0.17837		27
	0				–		28
			X		0.11849		29
	X				0.19561		30
0					–		31
	0				–		32
		X			0.16234		33
	X				0.64489		34
0					–		35
	0				–		36
		X			0.44492		37
	0				–		38
		X			0.22438		39
	0				–		40
		X			0.13074		41
	X				0.51588		42
0					–		43
	X				0.34559		44
0					–		45
	X				0.29197		46
0					–		47
	X				0.59536		48
0					–		49
	X				0.87958		50
0	1	8	15	1	n₁ = 25		X
1	8	15	1	0	n₀ = 25		0

WATTS	Functioning Levels (ζ)					FUNCT. TIME secs	RESISTANCE Ω	ITEM NO.
	1.19	1.27	1.39	1.49	1.60			
		0				–	.100	51
			X			–	.104	52
		0				–	.102	53
			X			0.72364	.105	54
		0				–	.100	55
			0			–	.106	56
				X		0.22631	.110	57
			X			0.43095	.100	58
		0				–	.105	59
			X			0.45608	.099	60
		0				–	.100	61
			X			0.82424	.110	62
		0				–	.090	63
		0				–	.095	64
				X		0.33169	.095	65
			X			0.33761	.096	66
		0				–	.092	67
			0			–	.098	68
				X		0.47852	.095	69
			0			–	.100	70
				X		0.39156	.097	71
			X			0.40023	.105	72
		0				–	.095	73
			0			–	.100	74
				X		0.19756	.097	75
			0			–	.105	76
				X		0.63491	.095	77
			X			1.18029	.095	78
		0				–	.100	79
		0				–	.091	80
				X		0.06355	.100	81
			X			0.41264	.095	82
		0				–	.099	83
			X			0.12832	.095	84
		0				–	.090	85
			X			0.81469	.094	86
		0				–	.095	87
			0			–	.100	88
				0		–	.104	89
					X	0.11133	.110	90
				X		0.17200	.101	91
			X			0.27081	.104	92
		0				–	.104	93
			X			0.38859	.097	94
		0				–	.100	95
			0			–	.095	96
				X		0.37996	.105	97
			0			–	.100	98
				X		0.40252	.105	99
			X			–	.100	100
	0	0	14	10	1	n₁ = 25		X
	0	14	11	1	0	n₀ = 25		0

i	i²	n₀	n₁	ζ watts
0	0	1	0	1.19
1	1	22	1	1.27
2	4	25	22	1.39
3	9	2	25	1.49
4	16	0	2	1.60
5	25			
6	36			

Totals: $N_0 = 50$ $N_1 = 50$

Special Parameters

c = (log ζ)$_{i_0}$ = .07555

d = (log ζ)$_{i+1}$ - (log ζ)$_i$ = .03

Primary Statistics

A = Σ i n

B = Σ i² n

M = (NB - A²)/N²

m = c + d (A/N ± ½)°

σ = 1.62 d (M + 0.029)√(N/(N-1)) ∞

°Use + for "o's; - for "x's
∞Valid for M ≥ 0.3 only, otherwise consult 'Brenton Report' (ASF Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1964) File No. M-1

	For "o's	For "x's
A =	78	128
B =	140	346
M =	0.36640	0.36640
m =	0.13735	0.13735
σ =	0.01917	0.01917

Secondary Statistics

m = (N₀ m₀ + N₁ m₁)/(N₀ + N₁) = .13735

σ = √((N₀ σ₀² + N₁ σ₁²)/(N₀ + N₁)) = .01917

ζ = Antilog m = 1.372 watts

Probability Levels	Confidence Level
P% = 99.9	X% = 90
100-P% = .1	

m = .13735	k_p ② = 3.090
σ = .01917	k_x ② = 1.282
d = .03	σ ③ = 1.085
S = α/d = .6390	σ² = 1.177
N = 100	H ③ = 1.262
n ① = 50	H² = 1.593

① n = N/2 when N is even integer

   n = (N+1)/2 when N is odd integer

② From BR°, p. 19, at given P or X

③ From BR° for G & H versus S.
   Use Graphs III & IV.
   When S ≥ .5, and Graph V
   When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right) \left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2} \sigma$$

= 0.01441

Final Calculations

(99.9%) (90% Conf) = m+k_p σ + Y

= .21099 log units

= 1.6355 watts

(.1%) (90% Conf) = m-k_p σ - Y

= .06370 log units

= 1.1579 watts

Probability Levels	Confidence Level
P% = 99	X% = 90
100-P% = 1	

m = 0.13735	k_p ② = 2.326
σ = 0.01917	k_x ② = 1.282
d = 0.03	σ ③ = 1.085
S = α/d = 0.6390	σ² = 1.177
N = 100	H ③ = 1.262
n ① = 50	H² = 1.593

① n = N/2 when N is even integer

   n = (N+1)/2 when N is odd integer

② From BR°, p. 19, at given P or X

③ From BR° for G & H versus S.
   Use Graphs III & IV.
   When S ≥ .5, and Graph V
   When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\frac{n+1.2}{n}\right) \left(\frac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2} \sigma$$

= 0.011386

Final Calculations

(99%) (90% Conf) = m+k_p σ + Y

= 0.19307 log units

= 1.5598 watts

(1%) (90% Conf) = m-k_p σ - Y

= 0.08162 log units

= 1.2067 watts

B-5 BRUCETON TEST MK 2 MOD 0 ELEMENT 30 MC

1.56	1.67	1.79	1.91	2.05	2.20	2.35	2.52	2.70	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
				O					–	.106	1
					X				.6180	.10	2
				O					–	.08	3
					X				.3432	.09	4
				O					–	.08	5
					X				.4813	.09	6
				X					.1185	.10	7
			O						–	.08	8
				X					1.0687	.08	9
			O						–	.08	10
				X					.6868	.09	11
			O						–	.09	12
				O					–	.08	13
					X				.5971	.08	14
				O					–	.07	15
					X				.3478	.09	16
				O					–	.08	17
					O				–	.08	18
					X				.0651	.08	19
				X					.8519	.07	20
				O					–	.08	21
				X					.2390	.09	22
				O					–	.08	23
					O				–	.09	24
					O				.2649	.08	25
					O				–	.08	26
					O				.4071	.09	27
				X					.4025	.09	28
				O					–	.08	29
					O				–	.08	30
									.1468	.08	31
					O				–	.07	32
						X			–	.08	33
						X			–	.08	34
						X			.6971	.08	35
					O				–	.09	36
						O			–	.11	37
							X		.0805	.09	38
						X			1.5161	.08	39
					O				–	.09	40
						X			.3565	.10	41
					O				–	.08	42
						X			.3863	.09	43
					O				–	.09	44
						X			.5093	.09	45
					X				.8791	.08	46
				O					–	.09	47
					O				–	.10	48
						X			.4498	.09	49
					O				–	.09	50
				0	3	9	10	2	n_x = 24		X
				3	10	11	2	0	n_0 = 26		O

1.56	1.67	1.79	1.91	2.05	2.20	2.35	2.52	2.70	FUNCT. TIME (secs)	RESISTANCE (Ω)	ITEM NO.
						X			.2097	.09	51
					O				–	.09	52
						X			.3970	.10	53
					X				1.7931	.09	54
				O					–	.09	55
					X				.8380	.10	56
				O					–	.09	57
					X				.6048	.09	58
				O					–	.10	59
					O				–	.08	60
						X			.1461	.10	61
				O					–	.09	62
						X			.4824	.09	63
					X				.7760	.10	64
				O					–	.09	65
					O				–	.10	66
						X			.2886	.09	67
					O				–	.11	68
						X			.3854	.09	69
					O				–	.08	70
						X			.2105	.11	71
					O				–	.09	72
						O			–	.08	73
							X		.1279	.10	74
						X			.1882	.09	75
					O				–	.09	76
						X			.5520	.09	77
					X				.5890	.09	78
				O					–	.09	79
					O				–	.10	80
						X			.7287	.10	81
						X			.7901	.12	82
				O					–	.10	83
					O				–	.09	84
						X			.4037	.09	85
					X				.5358	.10	86
				O					–	.09	87
					O				–	.11	88
						X			1.0666	.09	89
					X				1.6397	.11	90
				O					–	.09	91
					O				–	.09	92
						X			.4705	.10	93
					O				–	.08	94
						X			.1520	.10	95
					O				–	.10	96
						X			.2862	.09	97
					O				–	.08	98
						X			.4268	.09	99
					X				.4267	.09	100
					0	9	16	1	n_x = 26		X
					8	13	1	0	n_0 = 24		O

i	i²	n_o	n_x	ζ (w/ans)
.0	0	3	0	1.91
1	1	18	3	2.05
2	4	26	18	2.20
3	9	3	26	2.35
4	16	0	3	2.52
5	25			
6	36			
Totals:		$N_o = 50$	$N_x = 50$	

Special Parameters

$c = (\log \zeta)_{i=o} = 0.28103$

$d = (\log \zeta)_{i+1} - (\log \zeta)_i = .03$

Primary Statistics

$A = \Sigma\, i\, n$

$B = \Sigma\, i^2\, n$

$M = (NB - A^2)/N^2$

$m = c + d\,(A/N \pm \frac{1}{2})^*$

$\sigma = 1.62\, d\,(M + 0.029)\sqrt{\dfrac{N}{N-1}}$ **

*Use + for "o's;" - for "x's"

**Valid for M > 0.3 only, otherwise consult "Bruceton Report" (AMP Report No. 101.1R, "Statistical Analysis for A New Procedure in Sensitivity Experiments" July, 1944) File No. Ma-1

For "o's"	For "x's"
A = 79	
B = 149	
M = 0.48360	
m = 0.34343	
σ = 0.02617	

Secondary Statistics

$m = \dfrac{N_o\, m_o + N_x\, m_x}{N_o + N_x} = .34343$

$\sigma = \sqrt{\dfrac{N_o\, \sigma_o^2 + N_x\, \sigma_x^2}{N_o + N_x}} = .02517$

$\zeta = $ Antilog $m = 2.2051$ WATTS

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Probability Levels	Confidence Level	Probability Levels	Confidence Level
P% = 99.9	X% = 90	P% = 99	X% = 90
100-P% = 0.1		100-P% = 1	

m = 0.34343	k_p ② = 3.09	m = 0.34343	k_p ② = 2.326
σ = 0.02517	k_x ② = 1.282	σ = 0.02517	k_x ② = 1.282
d = 0.03	G ③ = 1.030	d = 0.03	G ③ = 1.030
$s = \frac{\sigma}{d} = 0.8390$	$G^2 = 1.0609$	$s = \frac{\sigma}{d} = 0.8390$	$G^2 = 1.0609$
N = 100	H ③ = 1.32	N = 100	H ③ = 1.32
n ① = 50	$H^2 = 1.7424$	n ① = 50	$H^2 = 1.7424$

① $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

---

① $n = \frac{N}{2}$ when N is even integer

$n = \frac{N+1}{2}$ when N is odd integer

② From BR*, p. 19, at given P or X

③ From BR* for G & H versus S. Use Graphs III & IV. When S ≥ .5, and Graph V When S < .5

Confidence Interval (Y)

$$Y = k_x \left(\dfrac{n+1.2}{n}\right)\left(\dfrac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2} \sigma$$

= 0.01965789

Confidence Interval (Y)

$$Y = k_x \left(\dfrac{n+1.2}{n}\right)\left(\dfrac{\sigma^2 + H^2 k_p^2}{n}\right)^{1/2} \sigma$$

= 0.0151327

Final Calculations

(99.9%) (90% Conf) = m + k_pσ + Y

= 0.44086 log units

= 2.7596 Watt

(0.1%) (90% Conf) = m - k_pσ - Y

= 0.24600 log units

= 1.76196 watt

Final Calculations

(99%) (90% Conf) = m + k_pσ + Y

= 0.41711 log units

= 2.6128 watt

(1%) (90% Conf) = m - k_pσ - Y

= 0.26986 log units

= 1.8614 watt

APPENDIX C

DRI SIMULATOR TESTS

C. RF TESTS ON SIMULATED MARK 2 MOD O IGNITION ELEMENTS FROM DENVER RESEARCH INSTITUTE

During the performance of this program the Denver Research Institute delivered to us 28 simulated MARK 2 MOD O ignition elements. These simulators consist of the standard MARK 2 MOD O assembly complete through the bridgewires, with a thermocouple substituted for the explosive. The elements were divided into four groups according to the spacing of the thermocouples above the bridgewires. The MARK 2 MOD O element has two paralleled bridgewires. The simulated elements have two thermocouples designated A and B - one for each of the parallel bridgewires. The spacings previously referred to are: very far (VF), far (F), medium (M), and close (C).

Tests were conducted at 5, 30, 250 and 1000 megacycles. These tests have shown that the simulated elements have an increase in thermocouple output as frequency is raised from 5 to 1000 megacycles. In some cases the output is considerably more than doubled, over this frequency range. At 5 megacycles, however, the output tends to level off to the dc value.

Data for millivolt output versus frequency are given in Table C-1. The simulators were all tested in the same RF systems used for the Bruceton tests of the complete MARK 2 MOD O ignition elements. Input power was set at the 50% mean fire level.

Curves showing output as a function of frequency for a limited number of simulators from the group of 28 are plotted in Figures C-1 and C-2.

A few of the DRI simulators were also tested with dc power applied to the bridgewires. The output was a linear function of dc input Figure C-3 displays this relationship.
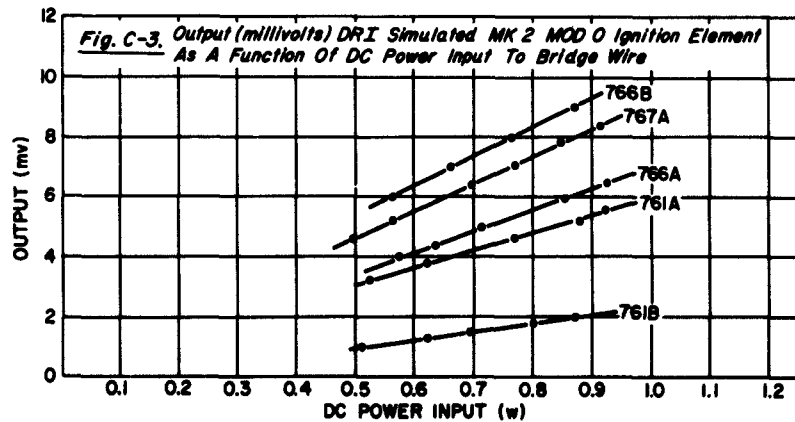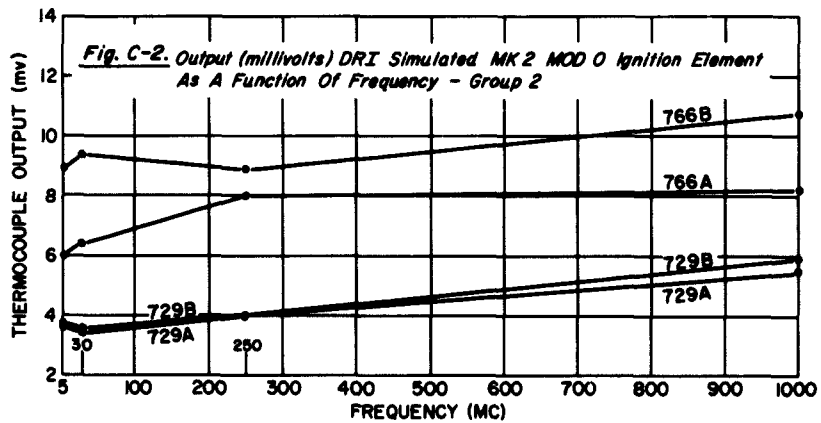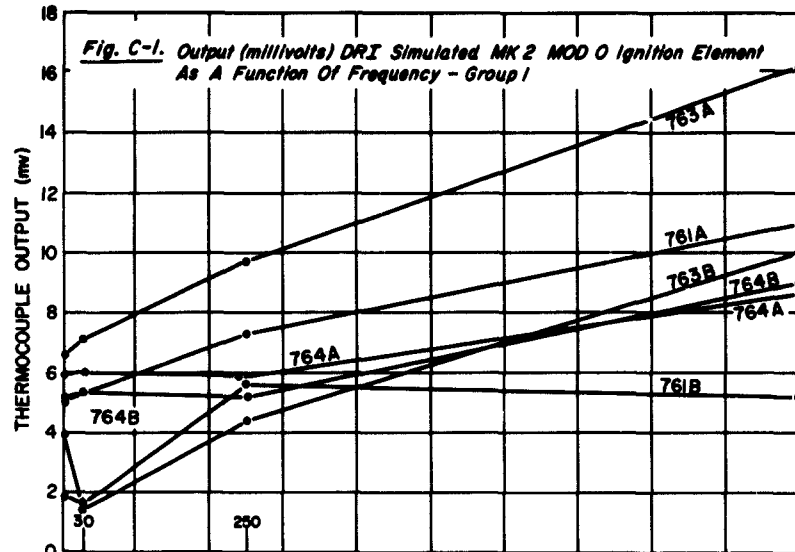
F-B1805

Table C-1

RF TESTS AT FRANKLIN INSTITUTE ON DRI SIMULATED
MARK 2 MOD 0 IGNITION ELEMENTS

Element Number	Thermocouple – Millivolt Output								Between Thermocouple and Bridgewire
	5 Mc		30 Mc		250 Mc		1000 Mc		
	Thermocouple		Thermocouple		Thermocouple		Thermocouple		
	A	B	A	B	A	B	A	B	
761	5.18	1.88	5.3	1.6	7.3	5.6	11.0	5.2	very far
763	6.55	3.90	7.1	1.4	9.7	4.4	16.2	10.0	very far
764	5.9	5.05	6.0	5.3	5.8	5.2	8.65	9.0	very far
766	6.0	8.9	6.4	9.4	8.0	8.9	8.2	10.8	very far
767	cut	open	7.8	6.6	9.5	9.2	12.0	13.1	very far
715	6.10	5.40	6.05	5.7	6.0	5.6	3.5	3.28	Far
724	0	9.6	0	9.6	7.9	10.0	0	13.7	Far
728	2.65	2.4	2.55	2.5	2.7	2.7	3.35	3.1	Far
729	3.6	3.7	3.4	3.45	4.0	4.0	5.5	5.9	Far
730	3.44	1.55	3.22	1.44	3.6	1.8	4.3	2.78	Far
733	6.00	3.2	5.81	3.1	11.0	4.5	11.4	9.0	Far
736	3.2	4.0	3.30	4.05	4.3	4.2	6.21	5.0	Far
740	5.58	3.3	5.70	3.35	6.4	4.1	7.66	8.1	Far
716	6.6	8.1	6.3	7.6	6.7	7.7	7.41	10.8	Medium
717	12.1	10.8	12.0	11.8	18.0	15.0	16.0	0	Medium
719	7.55	0	7.8	0	8.5	15.8	10.2	0	Medium
732	11.1	10.7	10.8	10.8	10.5	13.7	10.3	16.0	Medium
734	7.2	6.43	6.8	6.3	9.4	7.8	8.0	13.0	Medium
735	0	4.25	0	4.7	13.5	5.2	0	9.8	Medium
742	8.6	2.9	8.6	2.9	11.3	5.2	14.4	10.9	Medium
714	7.7	3.6	7.6	3.75	10.8	7.0	13.8	7.4	Close
718	4.7	5.45	4.8	5.10	5.0	5.2	5.9	6.0	Close
721	13.4	10.5	13.2	3.55	16.6	9.2	18.5	10.0	Close
727	Cut	open	0	0	0	4.0	0	11.0	Close
731	7.05	0	6.8	0	6.9	12.6	9.0	0	Close
737	3.15	6.2	3.15	5.9	6.0	8.5	Not Measured		Close
738	8.6	7.8	8.3	7.8	11.5	9.4	Not Measured		Close
741	9.1	7.9	8.8	8.2	11.5	11.5	Not Measured		Close

Fig. C-1. Output (millivolts) DRI Simulated MK 2 MOD 0 Ignition Element As A Function Of Frequency - Group I

Fig. C-2. Output (millivolts) DRI Simulated MK 2 MOD 0 Ignition Element As A Function Of Frequency - Group 2

Fig. C-3. Output (millivolts) DRI Simulated MK 2 MOD 0 Ignition Element As A Function Of DC Power Input To Bridge Wire

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